4

Plant cleaning, hygiene and effluent treatment

Cleaning aspects

4.1 Primary objectives

The keeping quality of yoghurt is governed by a multiplicity of interrelated factors such as:

- The hygienic quality of the product which, in turn, is dependent on the effective heat treatment of the milk base, the purity of the starter culture, the microbiological quality of added fruit/flavours and other ingredients and the care which is exercised during storage, handling and distribution of the yoghurt (see Chapter 10).
- The cleanliness of surfaces coming into contact with the yoghurt, e.g. processing equipment, filling machines and packaging materials.
- Miscellaneous, i.e. the hygienic manufacture of dairy products, the attitudes of the dairy personnel and the hygienic condition of the buildings/building site (IDF, 1980, 1984, 1985, 1987, 1991, 1992, 1994, 1996, 1997a,b; Wainess, 1982).

Factors related to some aspects mentioned above are discussed elsewhere, so that to achieve the primary objective, that is, an excellent yoghurt with good keeping quality, the remaining essential factor is the provision of hygienic processing equipment and packaging materials. The nature of contaminants from surfaces coming into contact with any food product, including yoghurt, could be physical, chemical or biological, and contamination from these sources can be minimised by the following approach (Swartling, 1959; Dunsmore *et al.,* 1981a, b; Dunsmore, 1983):

- removal of residues (milk, yoghurt and other additives) which can provide nutrients for micro-organisms remaining on the surfaces of equipment;
- cleaning and sanitisation/sterilisation of equipment by removal and destruction of micro-organisms which survived the removal of residues step;

Table 4.1 Soil characteristics of a yoghurt plant

Soil component on the surface to be cleaned	Solubility in water	Alkaline	Acids	Ease of removal during cleaning		Comments
				Without alteration by heat[a]	Effect of alteration by heat[b]	
I. Dairy						
Lactose	G	–	–	Good	Carmelisation/browning; more difficult to clean	Unlikely to take place during heat treatment of yoghurt milk
Fat	P (in solutions without surface active agents)	P	P	Good with surface active solutions	Polymerisation; more difficult to clean	Unlikely to take place during heat treatment of yoghurt milk since most types of yoghurt produced in the U.K. are low fat varieties; this condition may not arise
Protein	P	G	Av.	Poor with water; better with alkaline solutions	Denaturation; difficult to clean	This effect is most likely to take place during prolonged heating of milk, e.g. HTLT (see Table 2.15) or preparation of starter culture milk
Mineral salts	G-P	–	G	Reasonably good	Precipitation; difficult to clean	This effect is most likely to take place during prolonged heating of milk, e.g. HTLT (see Table 2.15) or preparation of starter culture milk

Table 4.1 *Continued*

Soil component on the surface to be cleaned	Solubility in water	Alkaline	Acids	Ease of removal during cleaning		Comments
				Without alteration by heat[a]	Effect of alteration by heat[b]	
II. Dairy additives						
Sweetening agent	G	–	–	Good	Caramelisation/browning; more difficult to clean	Condition may arise in the case of lactose hydrolysed milk heated at 85–90°C for >45 min, or if a high percentage of sugar is added to the milk base before heat treatment
Fruit	G-P	–	–	Good	Caramelisation/browning; more difficult to clean	This effect takes place in dairies that pasteurise their own fruit base before addition to yoghurt
Colouring or flavouring matter	G	–	–	Good	NA	
Stabilisers	[c]			[c]	NA	

(G) good; (Av) average: (P) poor; (NA) not applicable. HTLT, high temperature long time.

[a] Possible places of identification are: milk reception area, preparation of basic mix, yoghurt incubation tanks and/or yoghurt filling section. [b] Possible places of identification are: heat treatment section, multipurpose tanks, fruit processing equipment and/or bulk starter tanks. [c] Refer to text in Chapter 2.

Adapted from IDF (1979), Tamplin (1980) and Romney (1990).

- storage of equipment under conditions that limit microbial growth/survival when the equipment is not in use;
- removal of residual cleaning compounds which may contaminate the yoghurt.

The efficiency of plant hygiene/sanitation is, therefore, dependent on the performance of the cleaning and sanitation/sterilisation operations.

In the commercial situation, cleaning is the removal of yoghurt "soil" (Table 4.1) from the surface of the processing equipment, and this is followed by sanitation/sterilisation, that is, the destruction of most (sanitation) or all (sterilisation) of the residual micro-organisms; these aspects will be discussed in relation to the type of equipment used in the production of yoghurt and the degree of automation.

4.2 Principles of the cleaning process

The processing of milk during the manufacture of yoghurt forms different types of soiling matter on the surfaces of equipment (Table 4.1) and this soil consists of organic compounds (e.g. protein, fat, lactose and other non-dairy ingredients) and inorganic salts. The degree of deposition of the soil on the processing surfaces is governed by many factors, but is directly proportional to the amount of heat applied, which results in more denaturation of the milk proteins and more precipitation of the organic salts (from milk and water). Hence, soil resulting from the heating of milk is more difficult to remove than soiling matter from unheated milk. The factors that can affect fouling of processing equipment, including the cleaning of fouled surfaces have been reported by Grandison (1988), Fryer (1989), Bott (1990), Kessler and Lund (1990), de Jong *et al.* (1992), Jeurnink and Birkman (1994), Kastanas *et al.* (1995), Fryer *et al.* (1996), IDF (1997c), Tuthill *et al.* (1997) and Parchal (1997).

It is important that the processing equipment, including the pipelines, is properly emptied from yoghurt residues before commencing the cleaning programme. This approach ensures:

- reduced product losses (i.e. recovery >90%),
- minimum cleaning cycles,
- minimum milk solids discharge in effluents (i.e. environmental pollution) and reduce effluent costs,
- reduced costs of detergents/sterilisers and improved cleaning efficiency.

Recovery of the product from the process plant can be achieved by purging water through the installation, but this may lead to dilution of the yoghurt. Alternatively, purging a scraper through an automated plant before the cleaning cycle can achieve the same advantages. One example is the "pig" pipe scraper which is marketed by the Tuchenhagen company in Germany (Anon., 1993). The pig itself is made from an inert flexible moulding material that is wear resistant and compatible with both the product and the cleaning chemicals. The leading and trailing edges of the pig are equipped with scrapers that nest closely to the inside diameter of the pipe and, as a result, provide maximum scraping efficiency. A permanent magnet is moulded into the core of the pig and as the flux extends beyond the pipe wall, its location can be detected.

At either end of the process, a station is provided for the launch and recovery of the pig. The launching station has one air inlet and one exhaust valve situated behind

the normal parking position. In addition, the pig has a special cleaning location where it is retained by four pins. After removing the yoghurt from the pipelines, the cleaning fluid is introduced and the pins ensure turbulent distribution around the pig, thus leaving no dead pockets to harbour bacteria. The system is available with one or two pig scrapers for uni- or bidirectional use, respectively. Figure 4.1 illustrates the concept in more detail (see Bird, 1996).

The cleaning process necessitates the use of certain compounds referred to as detergents, which are available in liquid or powder forms. The basic functions of the detergents are:

- establishing intimate contact with the soiling matter through their wetting and/or penetrating properties;
- displacement of the soil, for example: by melting/emulsifying the fat by wetting, soaking, penetrating and peptising the proteins and by dissolving the mineral salts;
- dispersion or displacement of the undissolved soil by defloculation and/or emulsification;
- preventing redeposition of the soil by maintaining the properties of the above factors, and by ensuring good rinsing;
- miscellaneous, i.e. to be non-corrosive, to have no odour nor taste, to be non-toxic and non-irritable to skin.

In order to achieve the above properties/functions of a detergent different formulations are used. Table 4.2 illustrates some compounds, and their properties, that can be employed in the manufacture of a proprietary detergent.

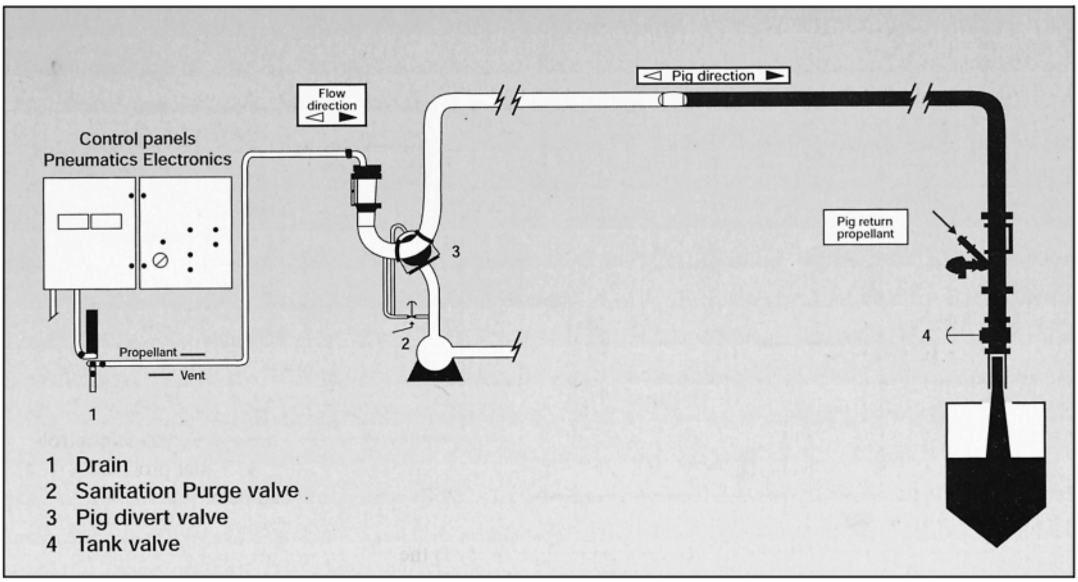

Fig. 4.1 “Pigging” system that reduces wastage during start-ups, shut-downs and product changeovers

Reproduced by courtesy of APV U.K. Co. Ltd., West Sussex, U.K.

Table 4.2 Functional properties and characteristics of detergent constituents

Type	Detergent components		I	II	III	IV	V	VI	VII	General comments
Inorganic alkalis	1. Sodium hydroxide		E	P	P	P			E	These compounds can affect degree of alkalinity, buffering action and rinsing power of a detergent.
	2. Sodium orthosilicate		G	F	F	P			G	For high alkalinity preparations use alkalis (1) and (2) which can cause skin irritation; therefore, handle them with care.
	3. Sodium metasilicate		G	G-P	VG	G			F	For removing heavy soil, alkalis (2), (3) and (4) are very effective.
	4. Trisodium phosphate		F	F-P	VG	G			F	For low alkalinity, i.e. mild or hand detergents, use alkalis (5) and (6).
	5. Sodium carbonate		F	P	P	P			P	
	6. Sodium bicarbonate		G	P	G	F			F	
Acids	Inorganic	Nitric acid Phosphoric acid Sulphuric acid								Acids are normally used for the removal of tenacious soil, e.g. in UHT plants.
	Organic	Hydroxy acetic acid Gluconic acid Citric acid	G			G				These materials are corrosive and can cause severe skin burns; therefore handle them with care, and if incorporated in a detergent formulation they may have to be used with corrosion inhibitors.
Surface-active agents	Anionic	Sodium alkyl aryl sulphonate Sodium primary alkyl sulphate Sodium alkyl ether sulphate		E	E	E				The classification is dependent upon how these compounds dissociate in aqueous solution, e.g. surface-active anions, cations, etc. Some of these compounds are also used as emulsifying agents.
	Non-ionic	Polyethenory compounds								Non-ionic agents do not ionise in solution.
	Cationic	Quaternary ammonium compounds (QAC)	(see sterilising agents below)							Surfactants tend to reduce surface tension of the aqueous medium and promote good liquid/soil/ surface interfaces.
	Amphoteric	Alkyamino carboxylic								

Table 4.2 *Continued*

Type	Detergent components	I	II	III	IV	V	VI	VII	General comments
Sequestering and chelating agents	Sodium polyphosphates	F	P	G	F	G			They prevent water hardness precipitation, are heat stable and are used for formulation of combined detergent/steriliser compounds.
	Ethylenediamine tetra acetic acid (EDTA) and its salts			VG	E	E	E	G	Their inclusion in formulations is to "hold" calcium ions in alkali solution and prevent reprecipitation. The bacteriostatic property of EDTA is achieved by withdrawing trace metals from bacterial cellular membranes.
	Gluconic acid and its salts					E	E		Gluconic acid is a stronger chelating agent than EDTA in alkali solutions (2–5% strength).
Sterilising agents	Chlorine: Chlorinated trisodium orthophosphate							E	Their inclusion provides a balanced product for cleaning (i.e. detergent) and sterilisation (e.g. hypochlorous acid, QAC, iodine or peroxide).
	Chlorine: Dichlorodimethyl hydration							E	Consult list of brands, approved by the authorities concerned, that can be used as detergent/sterilisers as an alternative to steam or boiling water for the sterilisation of dairy equipment.
	Chlorine: Sodium dichloro-isocyanurate								
	Chlorine: Sodium hypochlorite							E	
	QAC: Cetyl trimethyl ammonium bromide		VG	VG	VG			E	
	QAC: Benzalkonium chloride		VG	VG	VG			E	
	Iodine: Iodophors	G	G		G			E	
	Peroxide: Peracetic acid								
	Peroxide: Hydrogen peroxide								
Miscellaneous inhibitors	Sodium sulphite								These inhibitors minimise corrosive attacks by acids and alkalis on metal. The sulphites protect tinned surfaces, and silicates protect aluminium and its alloys from attack by alkalis.
	Sodium silicate								

Table 4.2 *Continued*

Type	Detergent components	I	II	III	IV	V	VI	VII	General comments
Antifoaming agents									Antifoaming agents are sometimes incorporated in a detergent formulation to prevent foam formation which could be generated by pumping/jetting action during detergent recirculation. Fats and alkalis may form soaps by saponification and these antifoaming agents prevent foam formation.
Suspending agents									Sodium carboxymethyl cellulose or starch assist in maintaining undissolved soiling matter in suspension, thus referred to as suspending agents.
Phosphates	Orthophosphates			G		G	G		Some of the polyphosphate compounds hydrolyse to orthophosphates in aqueous solution at high temperature, but presence of alkalis reduces the rate of hydrolysis.
	Polyphosphates			G		G	G		
Water softening									Precipitation of calcium and magnesium ions from hard water in order to avoid water-scale deposition on surfaces of equipment especially for the last rinsing step after cleaning.

(E) Excellent, (VG) Very good, (G) Good, (F) Fair, (P) Poor.
I, Organic dissolving; II, wetting; III, dispensing suspending; IV, rinsing; V, sequestering; VI, chelating; VII, bacteriocidal.
Data compiled from IDF (1979), Tamplin (1980), BSI (1970, 1977, 1984).

4.3 Factors involved in the selection and performance of a detergent

There are many different types of detergent available on the market and most of them have been developed for a specialised cleaning purpose.

4.3.1 Type/range of detergents used in the yoghurt industry

Different types of processing equipment are used during manufacture and the type of detergent is chosen in relation to its cleaning function, such as:

- *Mild detergents* are employed for manual washing operations.
- *Combined mild detergents/sterilisers* are similar to the detergent mentioned above, but with improved properties of sanitation.
- *Detergents for cleaning-in-place (CIP)* are extensive in number and they are divided into two basic categories, where no heating is applied and where heating is involved.

  Examples of milk processing equipment where no heating is applied are:
  - milk reception area
  - storage tanks and silos
  - equipment used for preparation of the milk base
  - incubation tanks
  - plate/tubular coolers
  - intermediate yoghurt tanks
  - filling machines
  - ultrafiltration (UF) or reverse osmosis (RO) plants

  Examples of cleaning equipment involved in the heat treatment of milk are:
  - heat exchangers
  - evaporators
  - bulk starter culture tanks
  - equipment for processing fruit.
- *Bulk liquid detergents* are similar to those mentioned above and are normally used by large dairies using automatically controlled CIP systems. They are in liquid form, since it is easier to dispense liquid into the cleaning cycle and control the concentration of the detergent.
- *Detergents for bottle washers* in the yoghurt industry are very limited, since most products are packaged in single-trip containers.
- *Detergents for churn washers* are used to protect certain metals (e.g. aluminium) since they tend to reduce the problem of corrosion and/or oxidation (i.e. dark or black discoloration of the aluminium surface).

Hence the choice of a detergent for a specific cleaning purpose and/or particular item of yoghurt processing equipment is directly related to its functional properties. Some suggested formulations are shown in Table 4.3.

4.3.2 Type of soiling matter

The soiling matter produced during the manufacture of yoghurt (Table 4.1) may be of two types, a soil which is easy to remove (for example milk and yoghurt) and a more difficult type of soil (for example, heated milk and/or fruit). It is obvious that

Table 4.3 Some examples of suggested detergent formulations (composition %)

Cleaning duty	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Bottle soak		14		68		6			8	4					
Bottle washer				95	5										
Dairy equipment cleaner (manual)						10	51	25				10		4[a]	
Milk can washing (machine)		20				12	26	40						2	
Milk can washing						10	51	25				10		4	
Pipeline cleaner		30				10	32	25						3	
Heavy duty CIP				95	5										
Dairy cleaner		7	18			8		15		46				6	
Vat cleaner	6	6						20		30	38				
Acid descaler													30	0.3	69.7
Acid cleaner												2	26		72
Acid cleaner (milkstone remover)													50	10	40

1, Sodium bicarbonate; 2, sodium carbonate; 3, sodium chloride; 4, sodium hydroxide; 5, sodium gluconate; 6, sodium metasilicate; 7, sodium sulphate; 8, sodium tripolyphosphate; 9, tetrasodium pyrophosphate; 10, trisodium phosphate; 11, metasilicate (crystals); 12, dodecylbenzene sodium sulphonate (LAS is 50% acidic); 13, phosphoric acid; 14, surfactant; 15, water.

[a] Non-ionic.

Data compiled from Cutler and Davis (1972), IDF (1979) and Tamplin (1980).

the choice of certain compounds to be incorporated into a detergent must take heed of the nature of these differing residues.

4.3.3 Water hardness and quality

Water is used during all the cleaning cycles in a processing plant and it is essential that two factors are considered. First, good quality potable water must be used (Table 4.4 illustrates some suggested standards for chemical specification and bacteriological quality), and second, the degree of hardness must be taken into account. This latter aspect is important, since detergents are formulated in relation to the degree of water hardness and the presence of excess inorganic salts, mainly calcium and magnesium, can reduce their effectiveness. In addition, these salts can leave deposits on the surfaces of equipment which are difficult to remove.

Water hardness may be of two types: temporary or permanent.

Temporary or carbonate hardness is due to the carbonates and bicarbonates of calcium and magnesium. These salts are easily precipitated or removed by heating; a typical example is scale formation on the inside of a kettle. In a yoghurt plant the same situation may arise in the evaporator and heat exchangers, since these sections are normally sterilised by circulating hot water (e.g. 85°C for 30–45 min). Deposits of calcium and magnesium salts on the surfaces of such equipment not only reduce the overall heat transfer efficiency of the plant, but can also provide a nucleus for other soil depositions to take place.

Permanent or non-carbonate hardness is due to formation of other types of calcium and magnesium salts (e.g. sulphates and chlorides). Their conversion into insoluble deposits is due to the presence of certain alkalis and, for this reason, specific constituents are incorporated into a detergent to minimise the precipitation.

Table 4.4 Some suggested chemical and bacteriological standards for water used in food processing plants

Chemical specifications		Bacteriological standards
Total hardness (as $CaCO_3$)	≤50 μg g^{-1}	(1) Throughout any year, 95% of samples should not contain any coliform organisms or *Escherchia coli* in 100 ml.
Chloride (as NaCl)	≤50 μg g^{-1}	(2) No sample should contain more than 10 coliform organisms per 100 ml.
Chloride (elementary)	≤1 μg g^{-1}	(3) No sample should contain more than 2 cells of *E. coli* per 100 ml.
pH	6.5–7.5	(4) No sample should contain >1 or 2 cells of *E. coli* per 100 ml in conjunction with a total coliform count of 3 or more per 100 ml.
Iron (as Fe)	1 μg g^{-1}	(5) Coliform organisms should not be detectable in 100 ml of any two consecutive samples.
Manganese (as Mn)	0.5 μg g^{-1}	
Suspended solids	Substantially free	

After Anon. (1969) and IDF (1979). Reprinted with permission of HMSO, London and International Dairy Federation, Brussels, respectively.

Table 4.5 Units for hardness of water and equivalent in degrees of hardness

Units	Earth alkali ions m val l^{-1}	Equipment in degrees of hardness			
		German°	English°	French°	US°
1 m val l^{-1} of alkali earth ions	1.00	2.80	3.5	5.0	50.0
German 1° = 10 mg CaO l^{-1} or 7.19 mg MgO l^{-1}	0.38	1.00	1.3	1.8	17.9
English 1° = 10 mg $CaCO_3$ 0.7 l^{-1}	0.27	0.80	1.0	1.4	14.3
French 1° = 10 mg $CaCO_3$ l^{-1}	0.20	0.56	0.7	1.0	10.0
US 1° = 1 mg $CaCO_3$ kg^{-1}	0.02	0.06	0.1	0.1	1.0

The expression val l^{-1} (g equivalent l^{-1}) is an alternative for equivalent weight l^{-1}, so that m val l^{-1} ≅ m EW l^{-1}; e.g. if the EW l^{-1} of $CaCO_3$ = 50 g l^{-1}, an m val l^{-1} = 0.05 g l^{-1}.

After IDF (1979). Reprinted with permission of International Dairy Federation, Brussels, Belgium.

The degree of water hardness is a measure of the mass of dissolved calcium and magnesium salts in the water, and according to Anon. (1967) and IDF (1979), the United States Geological survey classified water supplies as soft, moderately hard, hard and very hard if the total hardness (expressed as 1° = 1 mg $CaCO_3$ kg^{-1}; see Table 4.5) was 0–60, 60–120, 120–180 and over 180, respectively. However, water hardness is sometimes expressed in different terms/units/degrees in different countries, and Table 4.5 gives a comparison of the units used in Germany, the United Kingdom, France and the United States.

4.3.4 Miscellaneous factors

The formulation of a dairy detergent is also influenced by such factors as method of cleaning adopted and the materials used for the construction of the equipment, plant and other utensils; use of materials is discussed in Chapter 3.

4.4 Cleaning methods

The cleaning of any part of a yoghurt processing plant may involve one of the following methods: manual cleaning, cleaning-in-place (CIP) and miscellaneous cleaning methods. The basic steps involved in any of the above methods are somewhat similar. In principle they consist of the following operations.

In the *preliminary rinse* the processing plant, including starter culture equipment, filling machines and churns are rinsed with water to remove the bulk of the milk residues, yoghurt and/or fruit from the equipment. For conservation purposes, the final rinse (see below) is recovered, especially in large plants and used for this preliminary rinse.

In the *detergent wash* alkali compounds are usually used (refer to Tables 4.2 and 4.3 for specific applications) and during this stage the aim is to remove any adhering soil.

The *intermediate rinse* is to remove any detergent residues from the equipment prior to the operations acid wash and/or sterilisation/sanitation) that follow.

The *acid wash* cleaning operation is optional and may be performed only once a week to clean the heat processing equipment. It is important to point out that acids are harmful to the skin and hence an acid wash is normally used in CIP. Inorganic (nitric and phosphoric) and/or organic (acetic, gluconic, oxyacetic) acids may be used, since they have the ability to dissolve milkstone and remove hard water scale. Although phosphoric is only a medium-strong acid, both mineral acids are corrosive to certain metals (e.g. tinned steel). However, the organic acids do not pose the same problem, even at high concentrations. Nitric and other acids have good sanitising properties (Zall, 1990; Dunsmore, 1981; Dunsmore and Thompson, 1981; Lück *et al*., 1981; Dunsmore *et al*., 1981a, b; Wei *et al*., 1985; Lück and Gavron, 1990; Wildbret and Sauerer, 1990).

The *intermediate rinse* is to remove any acid residues from the equipment prior to the sterilisation/sanitation treatment.

Sterilisation/sanitation treatment of the plant and processing utensils must be effected before commencing production and this aim is achieved using one of the following:

- nitric acid
- chemical compounds (QAC, chlorine, chloramine to achieve sanitisation)
- heat (live steam is limited in its application, but hot water circulation at 85–90°C for 15–30 min is a valuable procedure; the temperature must be maintained on the return side of the plant and at the product outlet points) can produce sterile plant
- miscellaneous (refer to section on sterilisation).

In the *final rinse* good quality potable water is used to remove the sterilant residues from the processing plant. If hot water circulation is used for sterilisation, this stage

is obviously omitted, but the plant must be properly drained before production commences.

4.4.1 Manual cleaning

Some parts of a processing plant (e.g. utensils and filling machines) can only be cleaned by hand, while others, such as homogenisers and separators, if not designed to be cleaned-in-place, have to be dismantled and cleaned-out-of-place (COP) as indicated by Custer (1982). The sequence of hand cleaning is as follows: (a) disconnect and dismantle the equipment, (b) prerinse with potable tepid water at around 20–30°C, (c) prepare the mild/hand detergent solution at the appropriate concentration in water at 40–50°C, (d) brush/wash the various parts, (e) intermediate rinse with tap water, (f) sterilise using chemical agent, and (g) final rinse with water.

Factors which may influence the results of hand cleaning are:

- the human element which may manifest itself in the form of low detergent concentrations or inefficient scrubbing action;
- the temperature of the detergent solution may not be high enough;
- since chemical sterilisation is dependent on concentration and contact time, operators may overlook one or other of these factors.

Proper management, supervision and personnel training can all help to achieve the desired aims and discussion with the detergent manufacturer can also ensure that correct cleaning procedures are introduced.

Manual cleaning can also be improved by providing a cleaning-out-of-place (COP) tank, so that the cleaning operations are: (a) place the dismantled and prerinsed parts in the tank, (b) fill the tank with hot water, (c) add the correct amount of detergent, and circulate the hot detergent solution for up to 30 min, (d) drain detergent to waste or collect for other cleaning purposes, (e) rinse parts with continuous circulation of mains water, and (f) drain and sanitise/sterilise by submerging all parts in hot water or chemical sterilant.

The COP method could also be used for cleaning pipelines in a small dairy, or in those parts of a factory where it may be difficult to provide a proper CIP system.

4.4.2 Cleaning-in-place

This system of cleaning is engineered to clean processing equipment without dismantling and reassembling the different units and, in addition to minimising manual operations, the CIP system has proved beneficial in respect of:

- improved hygiene, possibly through a combination of the chemical action of the detergent and the physical action of the circulating solution(s);
- better plant utilisation;
- increased savings (of detergent, steam and sterilising agents);
- greater safety.

In order to make use of a CIP system, it is essential to have a closed circuit through which the cleaning solution(s) can be circulated. A typical basic unit is illustrated in Fig. 4.2. The design of any CIP system is tailormade for a specific cleaning objective, but the principal methods of CIP cleaning are classified into three basic

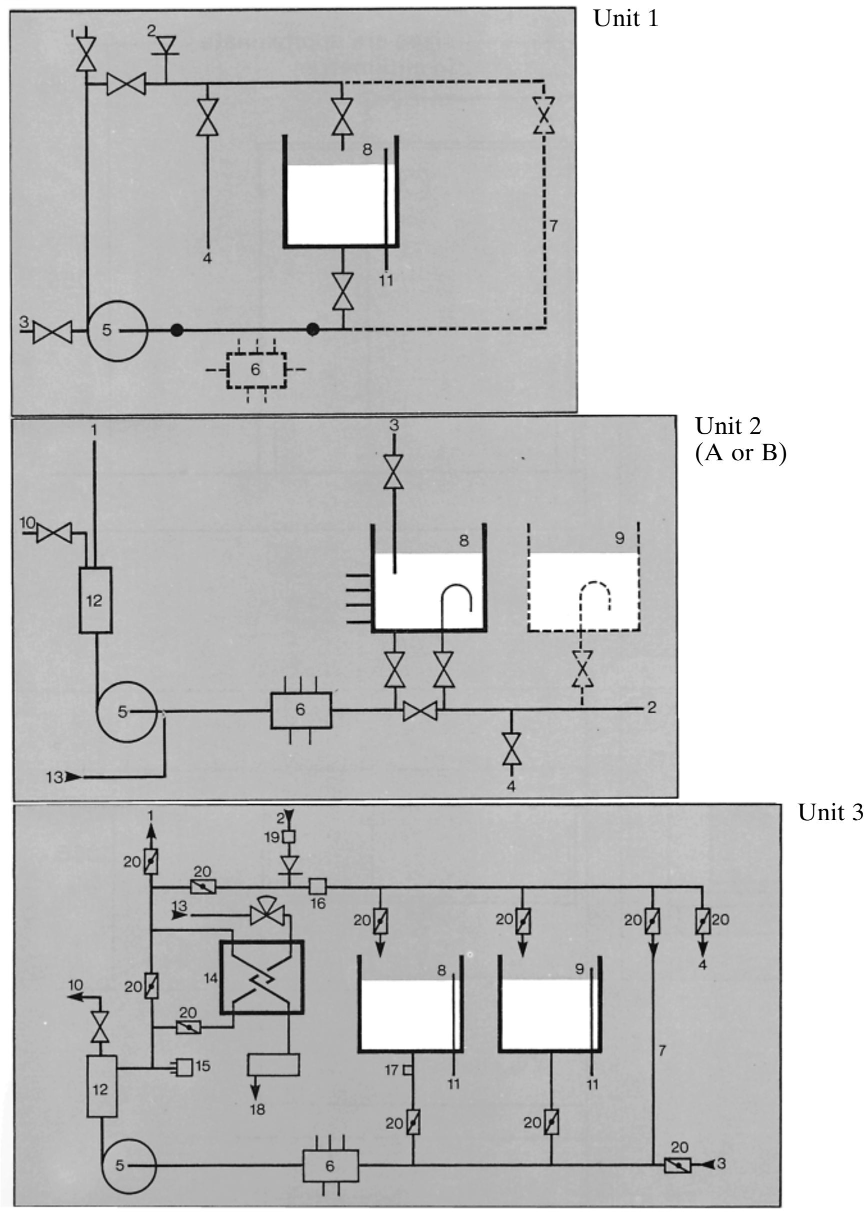

Fig. 4.2 Schematic illustration of APV Paraclean CIP systems

Unit 1, basic model; Unit 2, (A) single use package or (B) limited recovery option; Unit 3, multi-use system

1, CIP feed; 2, CIP return; 3, water inlet; 4, drain; 5, puma pump; 6, injection sleeve; 7, recirculating loop; 8, detergent tank; 9, water recovery; 10, sample cock; 11. overflow; 12, filter; 13, steam in; 14, paraflow heat exchanger; 15, temperature probe; 16, soluvisor; 17, conductivity probe; 18, condensate; 19, no-flow probe; 20, butterfly valve.

After Anon. (1997). Reproduced by courtesy of APV U.K. Co. Ltd., West Sussex, U.K.

systems: the single-use system, the re-use system and a combination of the two systems known as the multi-use system.

4.4.2.1 Single-use system

Unit 1 (Fig. 4.2) is basically small and is normally situated as close as possible to the equipment being cleaned. In a single-use cleaning system, the detergent is only used once and the washing solution is run to waste; this system is ideal for small plants.

The disposal of the detergent solution could be a disadvantage, especially if the strength and the functional properties of the solution are still available; however, after cleaning heavily soiled equipment in a large plant, it is the normal practice to discard the detergent solution after use because it has lost its strength. Such a system could be employed in a yoghurt plant, for example, for the cleaning of the bulk starter vats and/or multipurpose yoghurt tanks.

Figure 4.2 (Unit 2A) illustrates the basic components and the overall principle of the single-use system. However, these units can be supplied for automatic or manual operation, and can be further modified, that is, with the addition of a recovery tank (e.g. dotted tank in Fig. 4.2; Unit 2B), so that the wash solution and water rinse are recovered for the next preliminary water rinse; it is then known as the single-use system with a limited recovery option.

4.4.2.2 Re-use system

In this system, the detergent and/or acid solutions are recovered and re-used as many times as possible, especially in parts of the yoghurt plant where the equipment is not heavily soiled, for example in the milk reception area, the fortification/standardisation tanks and/or the yoghurt fermentation tanks. Thus, the preliminary rinse of such equipment removes a high percentage of the soil and, as the detergent solution circulated during the wash cycle is not heavily polluted, it can be re-used many times.

The re-use CIP system can be described as having these essential components: the detergent (Lye) tank(s), acid tank, water tank, water recovery tank and heating system, all interconnected with a system of pipework fitted with CIP feeds and return pumps. The concentration of the acid and lye solutions is regulated via feeds from tanks containing the corresponding compounds in a concentrated form, and the unit is also fitted with neutralisation tanks in which the lye and/or acid solutions are neutralised prior to their disposal into the effluent system. Furthermore, Tamplin (1980) and Romney (1990) pointed out that water consumption in a re-use system can be optimised by providing a recirculation facility for the hot water and the use of a return water tank. The on-site application of this system may be modified so that a low concentration of lye solution (0.5–1.0% caustic) is used for cleaning cold milk handling equipment, yoghurt fermentation tanks and the interconnected pipelines, while another lye tank contains up to 2% caustic for circulation during the cleaning of the milk processing plant.

Tamplin (1980) also pointed out that in a dairy operating 15–20 individual cleaning circuits per day, this CIP system becomes more efficient if another CIP feed pump is incorporated, so that two circuits can be cleaned simultaneously. However, any extension of the re-use CIP system is limited, since the tank capacity is defined in advance by the circuit volume, temperature requirements and desired cleaning

programmes; the latter aspect is fully automated in most processing plants, and the cleaning circuits are operated from a remote control panel.

4.4.2.3 Multi-use system
This system of CIP cleaning attempts to combine all the most desirable features of the single and re-use systems. The system is illustrated in Fig. 4.2 (Unit 3), and has the following features: (a) automatically controlled programmes for maximum flexibility, (b) not all cleaning liquids and/or solutions need be included in every cleaning programme (i.e. modular adaptability), and (c) economic features are low running cost, low water consumption and minimum effluent discharge (see Barron, 1987, 1988; Stack, 1997).

It can be observed that any of the above three CIP systems could be used for cleaning the yoghurt processing equipment (see Fig. 4.3 and 4.4; Jørgensen, 1993; Lyons, 1997), but the final selection of any one CIP system is governed primarily by factors such as:

- capital available for investment,
- desired degree of automation,
- estimated volume of yoghurt to be produced,

and hence, the final design may well be something of a compromise.

4.4.3 Miscellaneous cleaning methods

Alternative cleaning methods can be applied to suit special purposes and some examples of these have been reported by Haverland (1981), Chamberlain (1983) and Potthoff *et al*. (1997).

4.4.3.1 Soaking
Processing equipment and/or fittings are immersed in a cleaning solution at high temperature and after a soaking period of 15–20 min, the equipment is cleaned manually or mechanically. Unfortunately, no information has been given regarding the composition of the soaking agent, but it is possible that effective cleaning relies heavily on a digestion of the soil followed by a scrubbing action.

4.4.3.2 Ultrasonic treatment
This method of cleaning is a recent development on the soaking method discussed above. The equipment, utensils and fittings are immersed in a cleaning solution and any soil is lifted from the surfaces by the scrubbing action of microscopic bubbles generated by high frequency vibrations.

4.4.3.3 Spray method
This method of cleaning is widely used in the industry and involves spraying hot water or steam onto equipment surfaces *in situ*. The cleaning solution is sprayed from special units (portable or fixed) and its function is to remove as much heavily soiled matter from processing equipment surfaces as possible, before they are cleaned using one of the conventional methods.

4.4.3.4 Enzyme-based treatment
This method of cleaning does not employ conventional strong solutions of alkaline and/or acid components, but uses enzymes, surfactants, a buffer and complexing

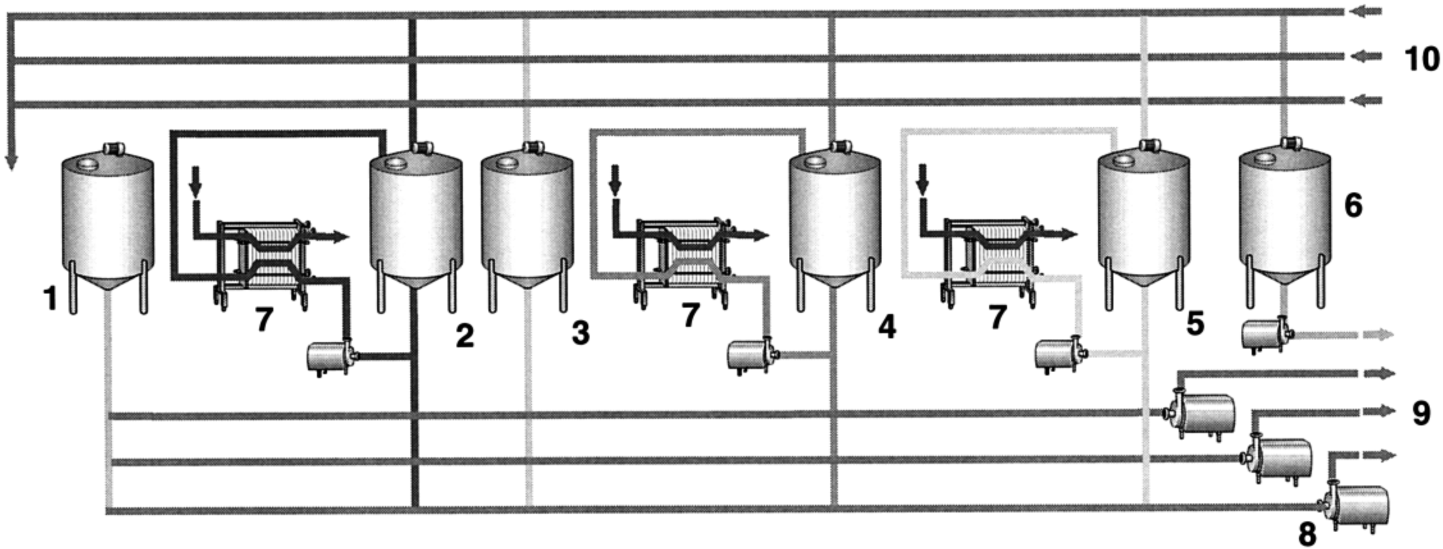

Fig. 4.3 Illustration showing the general design of a central CIP station

1, Cold water tank; 2, hot water tank; 3, rinse water tank; 4, alkaline detergent tank; 5, acid detergent tank; 6, rinse milk tank; 7, plate heat exchanger for heating; 8, CIP pressure pumps; 9, CIP pressure lines; 10, CIP return lines.

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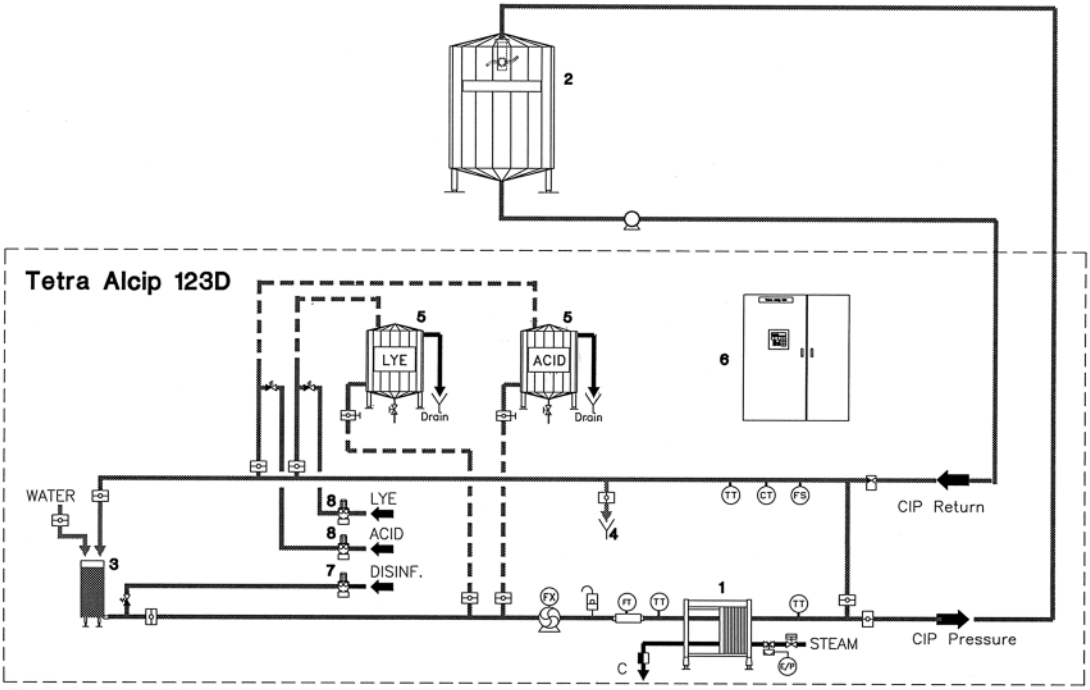

Fig. 4.4. Illustration of a CIP system for tanks and pipelines

1, Plate heat exchanger; 2, cleaning circuit (e.g. tank); 3, circulation tank; 4, drain; 5, detergent solution tank; 6, control panel; 7, metering pump for disinfectant; 8, metering pump for detergent concentrate.

TT: temperature transmitter; FS: flow switch; CT: conductivity transmitter; FX: frequency control; FT: flow transmitter.

Stage	Programme for ripening tanks	Time (min)	Temperature (°C)
1	Prerinse with water	3	ambient
2	Lye wash–1% caustic soda solution with complexing agent additive, to prevent scale precipitation and for improved dispersion	10	75
3	Intermediate rinse	1	ambient
4	Acid wash – 1% nitric acid solution	5	65
5	Final rinse with water, goes to rinse water recovery tank	5	ambient
6	Hot water disinfection, water goes to drain	6	>86

After Anon. (1995). Reproduced by courtesy of Tetra Pak (Processing Systems Division) A/B, Sweden.

agents with specific characteristics to remove soil from dairy processing equipment. Hence, the cleaning process takes place at a reduced temperature of 50–55°C, a high pH of 8.5–9.5 and at a low concentration of reagents (e.g. P3-Paradigm® is applied at 0.09% concentration; see Potthoff *et al.*, 1997). The enzyme hydrolyses any protein attached to the equipment surfaces and, as a consequence, the detached material will be evacuated with the main CIP flow. The buffer stabilises the pH, whilst the surfactant removes the fat and the complexing agent prevents scale build-up on the surface of the equipment. In addition, the final rinse contains a sanitiser

(e.g. P3-ParaDES®) that inhibits the growth of micro-organisms. Since such cleaning solutions are used at low concentrations, these components add very little to the biological oxygen demand (BOD) or chemical oxygen demand (COD) of the CIP discharge to the effluent from the dairy. Incidentally, one such cleaning agent has been developed by Henkel-Ecolab in Germany.

4.5 Factors influencing the efficiency of cleaning

The result of cleaning any type of processing equipment is dependent on a multiplicity of factors and some of these have been discussed by Milledge and Jowitt (1980), Haverland (1981), Bodyfelt (1981), Simard and Tastayre (1985), Sharp (1985), Timperley (1989), Ball (1990), Flagg and Thompson (1990), Romney (1990), Anon. (1992), Floh and Eng (1993), Timperley *et al.* (1994) and Bylund (1995).

4.5.1 Type of soil

Residues from milk that has been heat treated are more difficult to remove than those left behind by cold milk, and similarly residues from heat-treated fruits can adhere tenaciously to metal surfaces.

4.5.2 Method of cleaning adopted

Certain factors can be controlled much more effectively under the CIP system, for example, concentration and temperature of detergent, and hence the CIP system is more reliable and efficient, provided that the system is well maintained.

4.5.3 Contact time

Effective cleaning is time dependent, that is, the longer the contact time between the detergent and the soil matter, the cleaner the equipment will be after the cleaning cycle. However, the type of soil must not be overlooked. For example, 10 min is long enough (according to Anon., 1995) for a solution of 1% caustic soda at 75°C to clean the yoghurt fermentation tanks and pipelines (i.e. the soil is milk components), but the time has to be increased to 25 min when cleaning an ordinary milk pasteuriser (i.e. the soil of heated milk). Thus, contact time is important, since the functional properties of a detergent, for example, wetting, penetration, dissolving and suspending of soil, have a longer time to act.

4.5.4 Concentration of detergent solution

The concentration of the detergent solution used for manual cleaning is limited, since at high concentrations it may cause skin irritation, but in a CIP system, elective cleaning is improved with high detergent concentrations, although the law of diminishing returns comes into effect above a certain level. This ceiling

concentration, as applied to cleaning yoghurt processing equipment, would be in the region of 2–3%, since, as reported elsewhere, a caustic soda solution about 1% is sufficient for cleaning storage tanks, pipelines and yoghurt fermentation tanks; 1–<2% is recommended for cleaning multipurpose tanks and plate heat exchangers, and 2–3% for cleaning UHT plants.

It is important to monitor the strength of the detergent solution, especially in a re-use or multi-use system, but high detergent concentrations (i.e. above 2–3%) are not economic in a yoghurt processing plant. However, up to 5% may be necessary to clean a conventional evaporator if this approach is used to raise the total solids in the mix.

Acid solutions are normally used in the region of <1%, since at higher concentrations corrosion of metal surfaces may occur (see Fig. 4.4). However, with a bench-scale tubular heat exchanger (i.e. heating milk to 72°C) the use of a single-stage detergent system has been shown to produce clean surfaces both physically and chemically in half the time taken by a two-stage (i.e. alkali-acid) procedure which did not remove mineral deposits (Timperley and Smeulders, 1987, 1988). Ultimately under industrial operation, the choice of the cleaning system may differ when the yoghurt milk is heated to higher temperatures and held for longer periods.

4.5.5 Temperature

In general, the higher the temperature of the detergent solution, the more effective its cleaning action, so that while manual cleaning has to be carried out at around 45–50°C, the major sections of a yoghurt plant will be cleaned at 85–90°C using CIP; higher temperatures (e.g. 100–105°C) are used during the alkaline wash of a UHT plant. Acid treatments are usually carried out at around 60–70°C. Nevertheless, under certain conditions, for example, the use of enzyme preparation for cleaning purposes, the temperature of the CIP solution is ≤55°C (see Section 4.4.3).

4.5.6 Flow rate or velocity

The flow characteristics of a liquid in a pipe can be either laminar or turbulent and these configurations are influenced by such factors as pipe diameter, fluid momentum and fluid viscosity. A numerical presentation of the degree of turbulence in the fluid is referred to as its Reynolds number (e.g. *Re* 2000 = laminar, *Re* 2000–4000 = transitional and *Re* > 4000 = turbulent) and the higher the number, the more disturbed the flow. Thus, the physical scrubbing action in a CIP system is greatly influenced by the flow rate of the fluid, and effectiveness of the cleaning operation is greatly improved by increasing the velocity of the solution. Although the presence of any obstruction affects the flow rate of liquid through a plant, the mean velocity can still be calculated and Timperly and Lawson (1980) have substantiated that the residual bacteria on a surface are reduced to a minimum if the mean flow rate is maintained at $1.5\,m\,s^{-1}$, or as Kessler (1981) suggested $Re > 10^4$. However, the design and construction of any milk processing plant can affect the flow rate of liquids (i.e. milk base, yoghurt or detergents) and the mathematical equations used to measure these losses have been detailed by Romney (1990).

Silos and large storage tanks are cleaned using a CIP system and such equipment can be fitted with either sprayballs (Fig. 4.5) or rotating jets (Fig. 4.6)

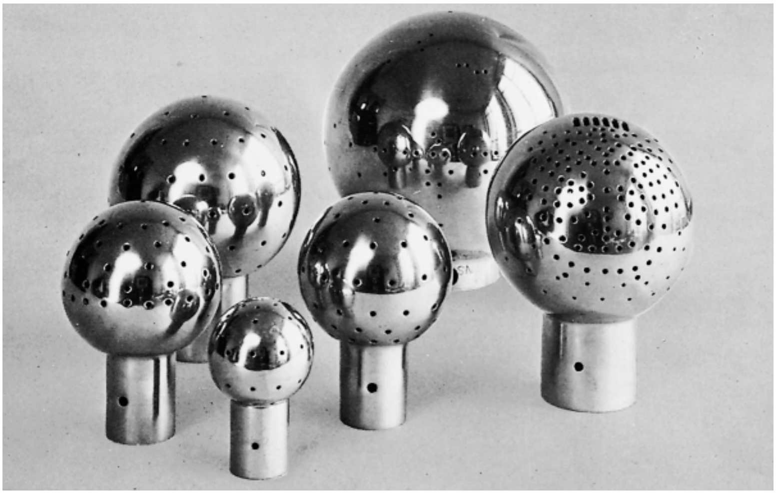

Fig. 4.5 Some different types of spray ball
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which help in distributing the CIP fluids. Tamplin (1980) compared these two basic types. Flow rates tend to be higher using sprayballs rather than rotating jets; this aspect could be important for achieving good results in cleaning. Romney (1990) has also detailed the various aspects involved in tank cleaning and currently the systems have been categorised according to their performance as follows:

- Category 1 – high pressure and low volume systems which tend to be used for tank cleaning; the heads have two nozzles as opposed to the four or eight available on large heads. The operating pressures range between 0.4 and 1 MPa, with corresponding flow rates from 3000–8000 l $hour^{-1}$.
- Category 2 – high pressure and high volume systems which are based on category 1 and are suitable for larger units; the operating pressures are between 0.6 and 1.5 MPa, and the flow rates from 8000 to 35 000 l $hour^{-1}$.
- Category 3 – low pressure and low volume systems. This category covers small fixed sprayballs and fixed jets, but not the rotating types; their application in dairies is restricted to those places where a very light cleaning duty is required.
- Category 4 – low pressure and high volume systems include the majority of tank cleaning heads, such as for milk silos and process buffer tanks; large flow, fixed spray balls and rotating spinner-type heads which use the reaction force of the jet to rotate the head are placed in this category.

4.5.7 Acid wash

Effective cleaning can also be dependent on the constituents of the detergent (see Table 4.2), and the acid wash is a supplementary cleaning process for the removal of milk stone and other types of soil. Whether or not the latter wash is conducted

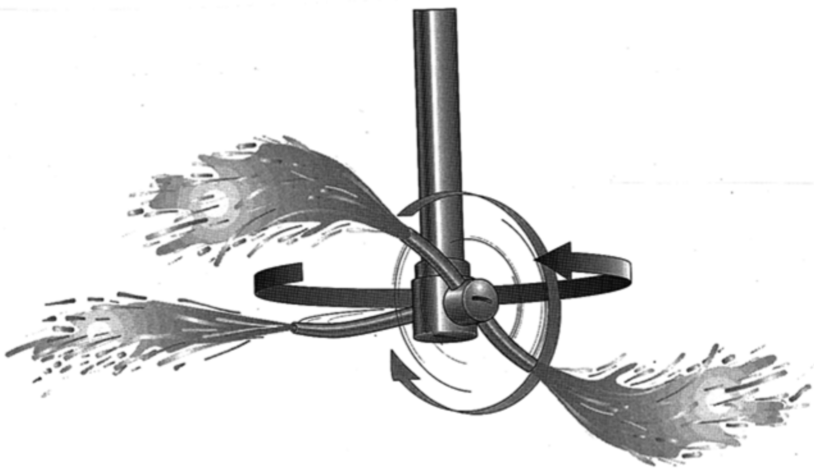

Fig. 4.6 Spray turbine for tank cleaning

The spray turbine consists of two rotating nozzles on the same pipe. One rotates in the horizontal plane and the other in the vertical. Rotation is produced by jet reaction from the backward-curved nozzles.

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regularly on a daily basis or once a week is subject to plant quality control and the final decision is based on microbiological tests.

4.5.8 Plant design

Any type of food processing plant, including a yoghurt plant, is constructed from a variety of vessels, pipelines, elbows, pipecouplings, valves and pumps. These components cannot be relied upon to be free from bacterial infection, and hence the efficiency of a cleaning programme may be dependent on plant design. Numerous factors are involved and according to the recent reviews of Lelieveld (1976), Milledge (1981), Timperley (1981), Timperley and Lawson (1980) and Romney (1990), the relevant factors could be summarised as follows: (a) corrosiveness of the stainless steel, (b) surface finish and surface grain (e.g. 80 μm average diameter grit had the effect of harbouring bacteria), (c) pipe couplings – the ring joint type (RJT) is unsuitable for CIP and the international sanitary standard (ISS) type can result in crevices that are difficult to clean, (d) good orbital welding is normally used for CIP circuits, but does not facilitate proper inspection, (e) dead pockets must be avoided, but if "T" pieces cannot be ruled out, the length must be kept short, (f) pumps are difficult to clean, especially reciprocating and positive displacement types, (g) valves are of three types – plug cock, plug and stem, and membrane; the latter two can be cleaned easily and sterilised by CIP, but not the plug cock type, and (h) plant layout.

Microbial attachment to milk contact surfaces has also been studied by Zoltay *et al.* (1981), Stone and Zottola (1985) and Bellon-Fontaine *et al.* (1990) using scanning electron microscopy. They confirmed that adhesion is influenced by such factors as metal roughness, surface treatments, welded seams, and the nature of any

rubber/plastic joints, and each can affect the efficiency of cleaning and sanitation of a processing plant.

4.5.9 Chemical composition of a detergent

It is often difficult to obtain the exact chemical composition of a given detergent, but some general data are given in Tables 4.2 and 4.3; however, according to Tamplin (personal communication), some typical commercial detergents have the following chemical composition.

(A) Detergent for cleaning silos and milk storage tanks ($g\,100\,g^{-1}$):

EDTA	25.0
Sequestering agents	2.5
Emulsifiers	1.0
Antifoam agent	0.5
Soaps	5.0
Water	66.0

The solution is used at a level of 0.2–0.5 ml or $g\,100\,ml^{-1}$ along with a level of 1–2.5 $g\,100\,ml^{-1}$ caustic soda at 60–90°C. Alternatively, if a blended product is used the composition ($g\,100\,g^{-1}$) is as follows:

Caustic soda	44
Sequestering agents	1
Water	55

and depending on the level of soiling, the concentration used would be 0.7–4 ml $100\,ml^{-1}$ circulated at 65–90°C.

(B) Detergent for cleaning a plate heat exchanger (PHE):

- Powder detergent ($g\,100\,g^{-1}$)

NaOH	30–50
EDTA	8–15
Trisodium phosphate	15–25

plus bulking agent (soda ash) and alkalinity booster (silicates), whilst the wetting agents are generally produced *in situ* by saponification; if required, a low foaming, non-ionic agent can be added; the recommended strength is 1–2 g $100\,g^{-1}$.

- Liquid detergent ($ml\,100\,ml^{-1}$)

NaOH (100° Tw. solution)	40–60
EDTA (30% concentration)	20–30
Silicates	55–15

plus other minor ingredients; such a detergent is used at a strength of 1.5–3 ml $100\,ml^{-1}$, and due to limited solubility of EDTA in NaOH (e.g. >50% NaOH), it is recommended that Na-gluconate be added as an organic sequestrant. The above detergent formulations are used in single-stage cleaning cycles,

but for two-stage cleaning (i.e. detergent/acid), the following might be more suitable.

- Powder detergent (g 100 g^{-1})

NaOH	60–80
EDTA	2–10
Phosphates	2–10

plus filler (soda ash) or liquid alkali [NaOH (100° Tw. solution) 85–95 ml 100 m^{-1}] and Na-gluconate (5–15 g 100 g^{-1}), whilst the acid could be 1 ml 100 ml^{-1} phosphoric acid.

(C) Combined detergent/sanitiser:
This type of product might include: Na-tripolyphosphates or calgon, Na-isocyanurate, chlorinated trisodium phosphate, silicate or soda ash for bulking (70%), and a chlorate tracer (a typical formulation (%) for use at 0.5% would be: phosphates 15, silicates 5 and soda ash 25–30). The latter compound ensures an available chlorine level of 250 μg g^{-1} at the maximum operating temperature of 50°C.

(D) High caustic EDTA blend:
This formulation is similar to the detergent described above for cleaning silos and milk storage tanks, but the chosen causticity and operating temperature is dependent upon water hardness (e.g. for a hard water condition, the phosphate concentration would be increased to 10–15%). Such a detergent would be used at a rate of 0.5–1%, and the microbiological "kill" is achieved by the combined action of causticity and temperature.

(E) Non-caustic alkaline detergent (%) followed by a sanitiser:

Soda ash	50–70
Silicate	30
Phosphate	5–12
EDTA	5–10

plus a low foam wetting agent; this non-caustic detergent treatment is normally followed by sanitisation with sodium hypochlorite at ambient temperature and a concentration of about 100–150 μg g^{-1} available chlorine.

(F) Acid detergent (%):

Phosphoric acid (81% conc.)	20–50
Non-ionic wetter	3–8

Formulations (C), (D), (E) and (F) could be used for cleaning yoghurt incubation tanks and/or silos or milk storage tanks and the recommended detergent is the "high caustic with EDTA" blend. Although the above detergent formulations may be out-of-date, in theory, the principle(s) and/or efficacy of cleaning dairy equipment may still be applicable to present day detergent formulations. Additional information has been reported by Wirtanen *et al.* (1997) who studied on-site efficiency of sanitisation in large dairy factories in different Scandinavian countries using different commercial detergent compounds.

4.6 Specific cleaning and sterilisation operations of yoghurt processing equipment and utensils

A comprehensive account of the cleaning and sterilisation of dairy plant and equipment has been published by British Standards Institution (BSI, 1970, 1977, 1984), and the relevant data, which are applicable to a yoghurt processing line, are illustrated in Table 4.6. Certain processing equipment, for example different types of heat exchanger, is used for the heat treatment of milk and the procedures of cleaning and sterilising ordinary high temperature short time (HTST) and ultra high temperature (UHT) units including yoghurt plants operating between 90°C and 110°C are shown in Table 4.7. However, membrane filtration plants (i.e. UF and RO) necessitate a different approach to cleaning. Table 4.8 illustrates the cleaning and sanitation procedures for those plants that are used in the dairy industry.

In general, the CIP system is used to clean the major sections of a yoghurt processing line and CIP programmes can be either manually operated or fully automated. Automatic control has been achieved during the past few decades using computers and microprocessors and, as a result, the process has become more efficient with better detergent recovery, a reduction in energy consumption and a reduction in the scope for human error. Many different types of computer are available on the market, but a review of these systems is unnecessary, since the layout, design and programme of a CIP system is basically tailormade to suit individual yoghurt plants.

However, CIP control systems offered by different manufacturers have certain advantages and the overall choice is governed by the level of capital expenditure and the degree of automation required. The programme of a CIP system may include up to 30 different functions for cleaning a tank or other processing unit, and the same programmes may also allow a prolonged cleaning operation to be introduced at certain times. Another feature which is common to these CIP control systems is the safeguard against power failure, and this precautionary factor is important, especially to accommodate a power failure taking place in the middle of a cleaning programme, otherwise the programmed function would be terminated.

Although the flexibility of any CIP controller system is assessed prior to making the final decision about which unit to install, some general points might be considered.

First, there must be no risk of the product becoming contaminated with the detergent and/or sterilant solutions. This safeguard can be achieved using one of the following systems:

- flow selector plate
- manual “key pieces” or “security flow pipes”
- use of special valves.

The former two systems are suitable for small plant operations and, as a further precautionary measure, interlock switches are often incorporated. The use of key pieces also offers a high degree of security, in that, for example, if installed at two places in a tank installation (bottom fed), the first will be positioned at the bottom when the product is being handled, while the second will be positioned at the top (i.e. above spray ball(s)) during the operation of the CIP programme. Alternatively, different types of mixproof valve could be used. A single-seat valve with external cleaning has one seat and two valves mounted on the same plug. The area between the

Table 4.6 Recommended methods for cleaning and sterilisation of yoghurt processing equipment

Equipment/utensils	Cleaning method	Sterilisation method
1. Milk cans/churns	*Manual wash* (a) Combined detergent/steriliser Rinse can with tepid water. Add 5 l detergent/steriliser solution at 40–50°C. Scrub thoroughly inside/outside surfaces of the can including neck and lid. Place can on its side and roll for ½ min. Allow at least 2 min contact time. Empty, rinse with clean water and invert to drain on a rack. Wash detachable can lids separately in a trough. (b) Detergent only Use same steps mentioned above.	(a) Chemical sterilisation Follow recommendations of detergent's manufacturer. (b) Steam (i) Steam chest = 96°C for 30 min. (ii) Steam jet – not less than 2 min.
	Machine wash (rotary or tunnel) Drainage stage for liquid milk residues. Prerinse with water (cold or at 40–50°C). Drainage stage(s). External wash with water at 40–50°C. Drainage stage. Jetting with solution of detergent at 70–80°C. Drainage stage(s). Rinse with water at 85°C (minimum). Live steam injection. Hot air drying at 95–115°C.	No sterilisation required
2. Weighing bowls and receiving tanks	Hose the bowls and receiving tanks with cold water and then with water at 50–60°C. Close outlet and add suitable volume of solution of general purpose detergent. Brush the internal and external surfaces, covers and strainers with suitable brush and as solution is drained from tank, scrub outlet valves and fittings. Hose tank and fittings with clean water, reassemble, the equipment is then ready for sterilisation.	(a) Combined detergent/steriliser Equipment is ready to be used immediately after final rinsing stage, or if this is not possible, resterilise immediately before use (b) Chemical sterilisation Prepare solution of sterilising agent. Partially fill weighing bowl and receiving tanks with solution of sterilising agent. Brush in same manner as indicated during "Cleaning method" using a brush reserved for this purpose. Rinse residues of sterilising agent from equipment by hosing with cold water and use equipment immediately; if this is not possible resterilise immediately prior to use.

Table 4.6 *Continued*

Equipment/utensils	Cleaning method	Sterilisation method
3. Pumps and pipelines	*CIP system* (refer to Table 4.7)	*For CIP use* (a) Hot water circulation for not less than 15 min measured from the time that all parts of circuit reach a temperature not less than 85°C. (b) Chemical sterilising agent – circulate solution, for example sodium hypochlorite, i.e. 50–100 $\mu g\ ml^{-1}$ of available chlorine at 20–40°C for contact period of 10–20 min; discharge and rinse with clean water and use immediately, if this is not suitable, resterilise prior to use.
	Manual wash Rinse with cold water. Dismantle and wash parts in trough filled with detergent solution. Brush all surfaces coming into contact with milk, and for pipes use long handled brush; brush pipes from both ends.	*For Manual use*: (a) Form pipework into closed circulation circuit and sterilise by one of the methods mentioned above (hot water or chemical sterilising agent). (b) Sterilise dismantled pipelines and fittings using steam for a period of 15 min. (c) Soak dismantled parts in solution of sterilising agent, rinse with cold water, reassemble immediately taking precautions to avoid recontamination; if equipment is not used immediately, resterilise immediately before use.
4. Milk/yoghurt processing plants	*HTST and UHT plants* (Refer to Table 4.7)	Refer to Table 4.7
	Batch type holding plants or (Milk is heated up to 95°C and held for 5 min) *Yoghurt multipurpose tank* Remove as much product as possible from the vessel. Fill with solution of sodium hydroxide-based detergent which may contain sequestering agent. Heat solution to 75–85°C by passing steam through the jacket, start the stirring mechanism and maintain temperature for 30 min. Drain cleaning solution from vessel. Rinse well with cold clean water. Sterilise. Note: should milk stone have accumulated in the vessel, treatment with a suitable acid (phosphoric acid of B.P. quality – 100 ml in 51 water at 40–50°C after the detergent wash has been rinsed) may become necessary.	Sterilise using one of the following methods: (a) *Steam* Connect low pressure steam supply to the outlet pipe of the vessel by means of screw couplings as a safeguard against accidents; using trailing hoses are dangerous and should not be used. Steam for a period of not less than 10 min after condensate temperature has reached temperature of 85°C. (b) *Alkaline solution* By means of CIP equipment, use 1% caustic solution at a temperature of not less than 75°C for minimum contact of 10 min. Rinse with cold clean water. (c) *Chemical sterilising agent* Use solution of sterilising agent as mentioned above.

Table 4.6 *Continued*

Equipment/utensils	Cleaning method	Sterilisation method
5. Homogenisers	*Part of the processing plant* (Refer to item 4 above)	(Refer to item 4 above)
	Separate unit Form all associated pipework including the homogeniser into a closed circuit. Reduce pressure from the homogeniser valve. Start up the homogeniser and rinse out circuit with water to remove loose milk residues; allow rinse water to go to waste. Pressure gauges, suction valves and inlet and outlet manifolds should be removed, cleaned and rinsed manually, and reassembled for sterilisation. Add sufficient detergent of type used on the main plant, or any specialised product for cleaning homogenisers, to about 90 l of water. Introduce detergent solution to the homogeniser and circulate for about 30 min at 70–80°C. Apply pressure of about 0.6 MPa. Leave all by-passes slightly open to allow passages of rinse water and detergent solution. Rinse with clean cold water to waste. Note: In prerinsing and final rinsing, the time of circulation should be kept to a minimum owing to the poor lubrication properties of water on the piston rods and hoses. No special precautions other than those mentioned are necessary when alkaline detergents are used, as these provide adequate lubrication.	Release pressure from the homogenising valves and introduce hot clean water. Continue circulation for a period of not less than 15 min after the return water has reached a temperature of 85°C. Note: (a) Ensure that all drain valves, pressure gauge line, etc., are raised to temperatures of 85°C for not less than a period of 15 min by bleeding the lines throughout the sterilising period. (b) The large mass of metal in the homogeniser blocks necessitates a long heating up period.
6. Filling machines	*Manual wash* At the end of the filling period rinse through with cold water, and wash away any product which has been rinsed on to the tracks. Dismantle removable parts. Rinse component thoroughly with cold water or at temperature 40–50°C. Clean all components manually with solution of a suitable detergent at 40–50°C. Rinse all components thoroughly with cold water until free from detergent. Reassemble the machine which is now ready for sterilisation.	(a) Combined detergent/steriliser. (b) Chemical sterilisation agent, e.g. sodium hypochlorite 50–100 $\mu g\, ml^{-1}$ of available chlorine at ambient temperature for contact period of not less than 10 min. (c) Hot water circulation for a period of not less than 15 min measured from the time effluent water reaches a temperature of 85°C. (d) Steam (not widely practised). Items (c) & (d) may not be applicable to all machines, therefore, before using any of these methods consult machine manufacturer.
	CIP wash If applicable, consult machine manufacturer for a recommended wash cycle.	As described in (a) to (d) immediately above. Follow the recommendations of the machine manufacturer.

Table 4.6 *Continued*

Equipment/utensils	Cleaning method	Sterilisation method
7. Starter culture tanks	*Manual wash* (a) Small size utensils of starter culture equipment can be washed by hand as described in item (1). (b) Vessels not equipped for CIP. Dismantle all removable parts and wash separately. Hose out the residual starter with cold water as soon as vessel is empty. Scrub surfaces with solution of mild alkaline detergent or detergent/steriliser at 40–50°C. Rinse with cold clean water and reassemble, the vessel is then ready for sterilisation.	Use one of the methods mentioned in item (4).
	CIP wash Start cleaning operation as soon as the vessel is empty, i.e. before the starter dries on to the surfaces. Carry out CIP using a suitable alkaline detergent or detergent/steriliser solution; pay particular attention to outlet valve. Rinse with clean water in accordance with the starter vessel manufacturer's instructions. The vessel is then ready for sterilisation.	Use one of the methods mentioned in item (4).
8. Vessels for bulking fruit	These may be used in large-scale yoghurt production, and the cleaning cycle may comprise: Rinse thoroughly with water at 40–45°C. Scrub with milk detergent. Rinse with cold clean water. The vessel is ready for sterilisation.	Use one of the methods mentioned in item (4).
9. Miscellaneous	(a) Glass bottles and crates. Follow recommendations provided for washing/sterilisation of returnable glass milk bottles. (b) Membrane (UF & RO) machines. (c) Single effect evaporator Follow instructions of equipment manufacturer; one such unit is used as illustrated in Chapter 3 and the evaporator is cleaned with the rest of the processing equipment.	 See Table 4.8 See Table 4.7

Adapted from BSI (1970, 1977). Reprinted with permission of British Standards Institution, London, U.K.

Table 4.7 Cleaning and sterilisation method for milk and yoghurt processing plants[a]

Types of processing plant	CIP programme	
	Detergent wash	Sterilisation
HTST[b] (pasteurisers)	Rinse with cold water for 15 min. Circulate detergent solution at 70–80°C for 20 min. Rinse with cold water. Note: Change flow from "forward" to "diversion" during the detergent wash. Plates may be opened, brushed and hosed with water. An occasional acid wash is carried out after the alkali wash, since a straightforward acid wash may cause corrosive damage to stainless steel.	(a) Hot water circulation (not less than 15 min from the time that all sections of the plant reach temperature not less than 85°C – operate flow diversion valve frequently during the circulation period). (b) Chemical sterilising agent (see Table 4.10).
UHT[b]	Rinse with cold water for 15 min *Alkali wash* • Primary stage Circulate 3% solution of mixed alkali for 30 min at 100–105°C; change flow from "forward" to "diversion" at intervals; flush out alkali solution and rinse with water. • Secondary stage Circulate 2% solution of alkali containing a high proportion of a calcium sequestering agent for 30 min at 100–105°C; flush alkali solution and rinse with water. • Alternative method Circulate higher strength of detergent solution containing high proportion of calcium sequestering agent. *Acid wash* Circulation of 0.5% acid solution for 30 min at 75–80°C. Rinse with clean cold water. Plates may be opened, brushed down and hosed with cold water.	UHT plants are frequently sterilised automatically. Alternatively, circulate pressurised hot water at temperature not less than 140°C and not more than 150°C for a period of not less than 15 min and use plant immediately; or steam under pressure. Note: Ensure that all sections of the plant are within temperature range from 140–150°C; Temperatures greater than 150°C may cause rapid deterioration of rubber joints; Chemical sterilisation agents are not suitable.

Table 4.7 *Continued*

Types of processing plant	CIP programme	
	Detergent wash	Sterilisation
Yoghurt/equipment	*First example* (Time/temperature relationship is 85°C for 6–10 min). Rinse with cold water for 20 min; open the holding tube and scrub by hand, and finally rinse with water for 5 min. Detergent wash (2% caustic for 30 min at 85–90°C). Flush out detergent and rinse with cold clean water for 20 min; open holding tubes for visual inspection. Once a week carry out acid wash (1% phosphoric acid) following the detergent wash at 85–90°C for 30 min; also once a week open the plates and check.	Hot water circulation for 30 min at 85–90°C; or steam under pressure for UHT yoghurt plants.
	Second example (Time/temperature relationship is 90°C for 2–5 min). Preliminary cold water rinse for 3–5 min. Detergent wash (1% concentration for 6 min at 65–75°C). Final cold water rinse for 6 min. Note: Perhaps once a week use an acid rinse (1% concentration) for 6 min carried out after flushing out the detergent and rinsing with cold water; also carry out water rinse after the acid wash.	Hot water circulation for 20 min at 90–95°C.
	Third example (Time/temperature relationship is 115°C for 3 s). Preliminary cold water rinse for 5 min. Detergent solution (2% caustic) with circulation for 45 min at 85°C. Intermediate water rinse for 5 min. Acid solution ($1\frac{1}{2}$–2% phosphoric acid) circulation for 45 min at 70°C. Final rinsing with cold water for 5 min.	Hot water circulation for 20 min at 85°C.

[a] These are plate heat exchanger plants; batch processing plant is discussed in Table 4.6.

[b] Data compiled from BSI (1970, 1977, 1984). Reprinted with permission of British Standards Institution, London, UK.

Table 4.8 Recommended procedure for the cleaning and disinfection of UF and RO plants

Equipment	Cleaning and disinfection programme
UF plant fitted with spiral wound membranes used for processing skimmed milk	Rinse/flush the plant with water (5–15 min) until all the product has been removed. Detergent wash by recirculating a solution of 1.2% P3-Ultrasil 11 (Henkel-Ecolab) at 50°C for 30 min. Rinse/flush the plant with water (5–15 min) until the detergent has been removed. Acid clean by circulating 0.3% nitric acid solution (P3-Ultrasil 75) at 50°C for 20 min. Rinse/flush the plant with water (5–15 min) until acid has been removed. Detergent cleaning in which solution of 1.5% P3-Ultrasil 141 and 150 $\mu g\,g^{-1}$ sodium hypochlorite at 50°C is circulated for up to 40 min. Rinse/flush the plant with water (5–15 min) until detergent has been removed. Disinfection by circulating a solution of 2.5 $mg\,g^{-1}$ sodium metabisulphite or 1.5% P3-Ultrasil 73 at 25°C for 15 min. Stop the plant. Rinse/flush the plant with water (5–15 min) before next production.
RO plant with spiral wound membranes	Rinse the plant with water until product has been removed. Detergent wash by recirculating a solution of 1% Divos 100 (Diversey Lever) at 50°C for 30 min. Acid clean by circulating 1% Divos 2 at 50°C for 20 min. Rinse/flush the plant with water or RO permeate. Enzymatic cleaning in which solution of 1% Divos 98PE is circulated at 50°C for 1 h. Rinse/flush the plant with water or RO permeate. Disinfection by circulating a solution of 0.6% Divos 2 at 50°C for 20 min. Stop the plant. Rinse/flush the plant with water before next production.

After Kønigsfeldt (personal communication).

two seals is open to the atmosphere and this leakage drain chamber is closed by a small shut-off valve before the seat valve is activated; an external CIP line is connected to the drainage line via the small valves (see Fig. 4.7 and Bylund, 1995). A double-seated valve (with external cleaning or seat-lift cleaning) has two independent seals separating the two liquids and a drainage chamber in between (see Fig. 4.7 and 4.8). This chamber must be open to the atmosphere to ensure full mixproof safety in case either of the two seals should leak. When a double-seated mixproof valve is activated, the chamber between the upper and lower body is closed and then the valve opens to connect the upper and lower pipelines. When the valve is closed, first the upper plug seals and then the leakage chamber is opened to the atmosphere. This gives very small product losses during operation. It is important that the lower plug should be hydraulically balanced to prevent pressure shocks from opening the valve and allowing products to mix. During cleaning, one of the plugs lifts, or an external CIP line is connected to the leakage chamber. Some valves can be connected to an external cleaning source for cleaning those parts of the plugs which have been in contact with the product.

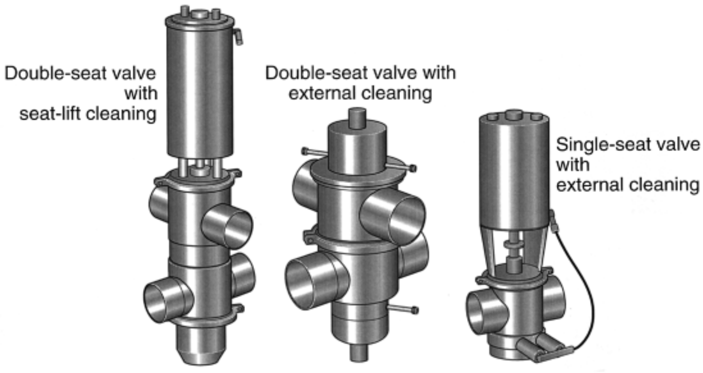

Fig. 4.7 Illustration of three types of mixproof valve

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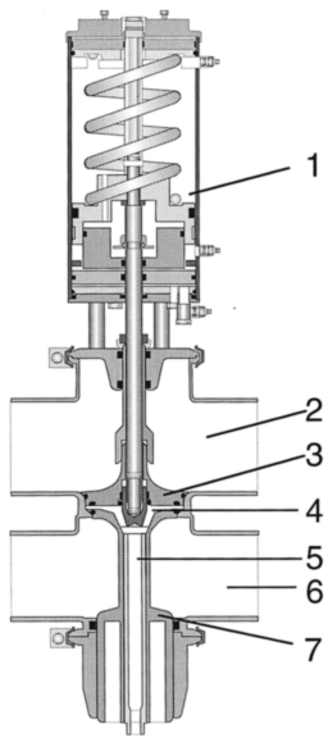

Fig. 4.8 Detailed illustration showing the assembly of a double-seat mixproof valve with balanced plug and built-in seat lift

1, Actuator; 2, upper port; 3, upper plug; 4, leakage chamber with drainage; 5, hollow spindle to atmosphere; 6, lower port; 7, lower plug with balancer.

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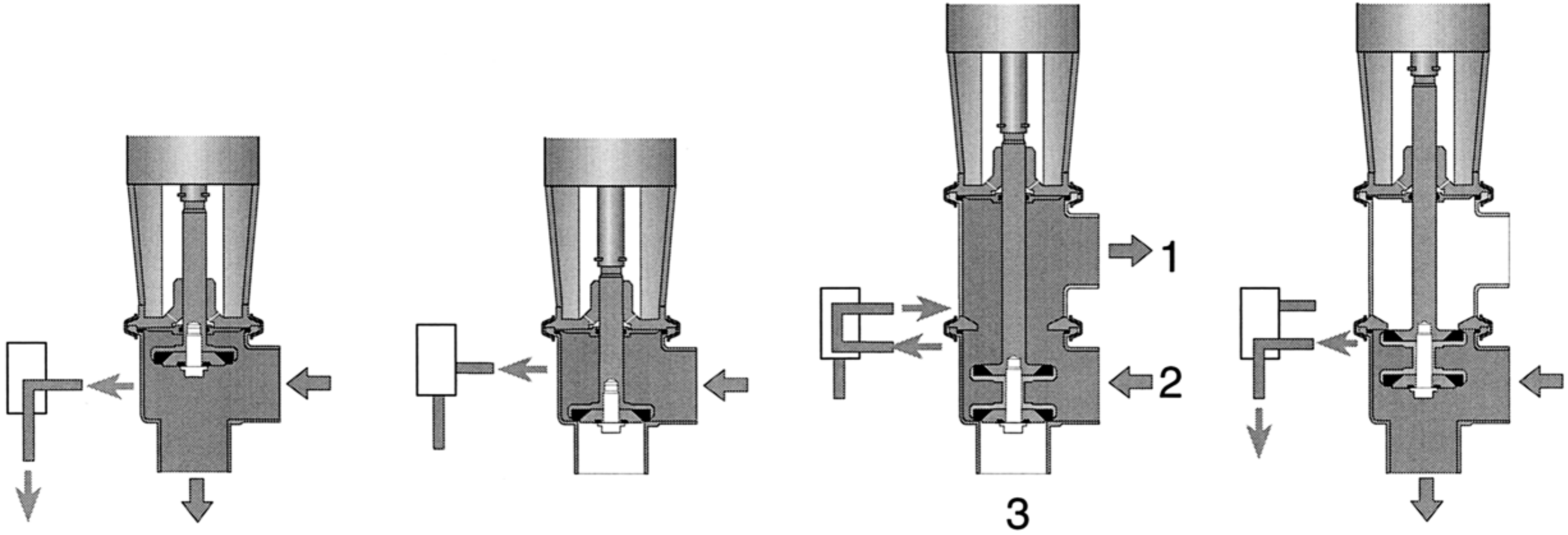

Fig. 4.9 Shut-off and change-over valves with plug in different positions

This valve has between three and five ports; when the plug is lowered the liquid flows from inlet 2 to outlet 1, and when the plug is lifted to the upper seat, the flow is directed through outlet 3 (see right hand drawing).

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The three-way valve is a single valve which is arranged in such a way that, in the closed position, one part is open to the atmosphere and any leakage of the CIP solutions will fall outside the vessel; thus contamination of the product is prevented. However, a double-valve system with electric interlocks has been developed which ensures total isolation of the circuit being cleaned from the adjacent section where product could be flowing (Fig. 4.9).

Second, a good drainage system must be in place so that the product and/or cleaning solutions can be quickly removed from the plant to prevent intermixing. Therefore, sound design of a plant is essential and the piping layout must have the following features:

- self-drainage capability,
- no parallel flow (i.e. the detergent flows in the opposite direction to the product),
- no dead ends.

Third, in modern yoghurt installations, the "pigging" system is employed to purge the product from the pipelines in order to improve cleaning efficiency (see Fig. 4.10). However, in older installations air purging is used to purge the yoghurt. A blast of oil-free compressed air is forced into tanks and pipelines as a convenient method of evacuating residual product (e.g. milk or yoghurt) from the plant; the volume of air delivered and the duration of purge is calculated to empty the pipelines

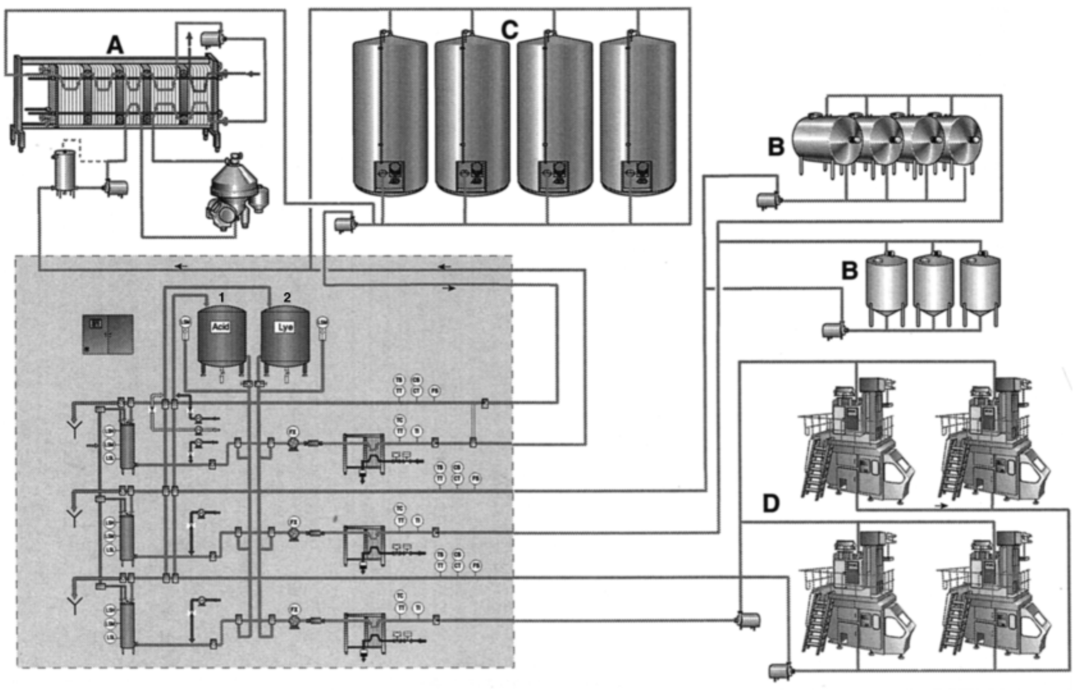

Fig. 4.10 The centralised CIP system

A. Milk treatment; B, series of tanks; C, silos; D, filling machines.
1, Acid detergent tank; 2, alkaline detergent tank.
Central CIP station is located within the dotted lines in the figure.
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effectively. The result is improved product recovery, minimum soiling matter to be removed and less rinsing water required, and better utilisation of detergent since elective concentrations can be maintained for a number of runs. Incidentally, although the air purging system is mainly operated before the cleaning cycle commences, it is also used to evacuate residual rinsing water during and/or after cleaning (e.g. the preliminary rinse at the beginning of the cleaning cycle).

Fourth, in large plants the CIP system itself will need to be cleaned occasionally, and the usual approach is to install a separate CIP system for cleaning the main installation. The main problem arises from the precipitation of milk protein in the detergent tanks.

Fifth, specific data regarding the CIP of yoghurt filling machines are not available, but Langeveld *et al.* (1982) evaluated the efficiency of a CIP system in removing secondary contamination from a Hamba-2000 filling machine; they concluded that the CIP programme was satisfactory. This particular CIP programme included a prerinse with water, circulation of an alkaline solution at 70°C for 20 min, and finally rinsing with water containing 1 μg of free chlorine ml^{-1}.

Sixth, the design of the CIP station is determined by many factors (Bylund, 1995) such as:

- How many individual CIP circuits are to be served from the CIP station?
- Are the milk base and/or yoghurt rinses to be collected, and/or processed for reuse or discharge?
- What method of sterilisation of the equipment to be used (i.e. chemical, steam or hot water)?
- What method of detergent system is to be used – single or multistage?
- What is the demand for steam for cleaning and sterilisation purposes?

Thus, two types of CIP systems can be used, centralised cleaning and decentralised cleaning. The former system (see Fig. 4.10) is normally used in small dairy plants with relatively short CIP pipelines. The detergent solutions and hot water are kept hot in insulated tanks and the required temperatures are maintained by heat exchangers. The final rinse water is collected in the rinse-water tank and is used as prerinsing water in the next cleaning programme; the milk/water mixture from the first rinse is collected in the rinse-milk tank. The detergent solution must be discharged when it has become dirty after repeated use, and the storage tanks must then be cleaned and refilled with fresh solutions. It is also important to empty and clean the water tanks, especially the rinse-water tank, at regular intervals to avoid the risk of infecting an otherwise clean process line.

A station of this type is usually highly automated. The tanks have electrodes for high and low level monitoring and the quality of the returning cleaning solutions is controlled by conductivity transmitters. The conductivity is proportional to the concentration of the active ingredient and at the phase of flushing with water, the concentration of the detergent solution becomes lower. At a preset value, a changeover valve routes the liquid to drain instead of to the relevant detergent tank. CIP programmes are controlled by a computerised sequence controller and large CIP stations can be equipped with multiple tanks to provide the necessary capacity.

Decentralised CIP is an attractive alternative for large dairies where the distance between a centrally located CIP station and peripheral CIP circuits would be extremely long (see Fig. 4.11). The large CIP station is replaced by a number of smaller units located close to the specific groups of process equipment in the dairy,

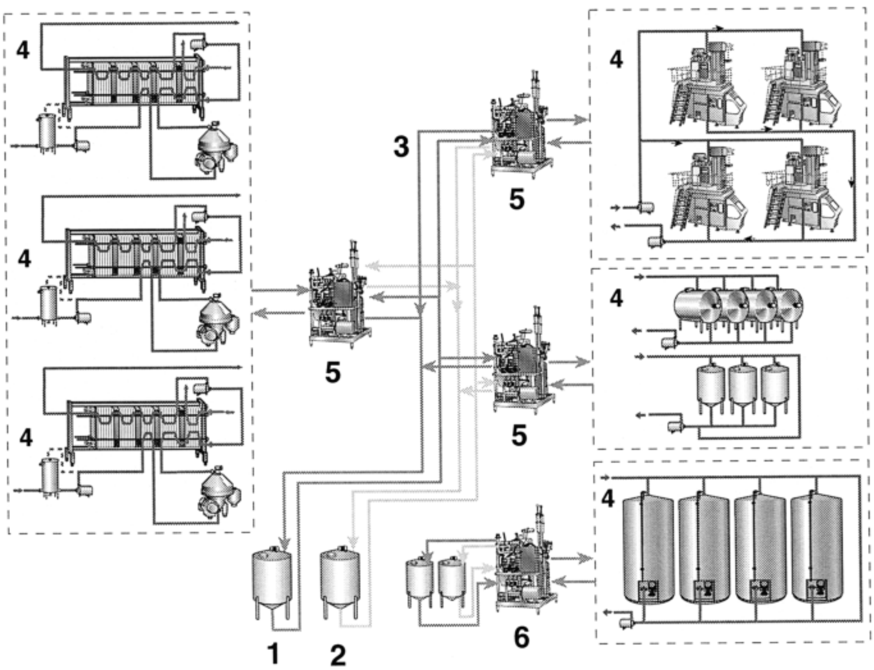

Fig. 4.11 Illustration of decentralised or satellite CIP system

1, Alkaline storage tank; 2, acid storage tank; 3, pipelines for detergents; 4, equipment to be cleaned; 5, satellite CIP units; 6, decentralised CIP system with its own detergent tanks.

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but there is still a central station for storage of the alkaline and acid detergents which are distributed to the individual or satellite CIP units. The supply and heating of rinsing water (and acid detergent when required) is arranged locally at the satellite stations. These stations operate on the principle that the various stages of the cleaning programme are carried out with a carefully measured minimum volume of liquid – just enough to fill the circuit to be cleaned. A powerful circulation pump is used to force the detergent through the circuit at a high flow rate.

The principle of circulating small batches of cleaning solutions has many advantages. Water and steam consumption, both momentary and total, can be greatly reduced. Milk residues from the first rinse are obtained in a more concentrated form and are, therefore, easier to handle and cheaper to evaporate. Decentralised CIP reduces the load on sewage systems compared to centralised CIP, which uses large volumes of liquid.

The concept of single use detergents has been introduced in conjunction with decentralised CIP, as opposed to the standard practice of detergent recycling in centralised systems. The one time concept is based on the assumption that the composition of the detergent solution can be optimised for a certain circuit. The solution is considered spent after having been used once. In some cases it may, however, be used for prerinsing in a subsequent programme.

Sterilisation aspects

4.7 Fundamentals of the sterilisation process

Milk and/or yoghurt soiling matter on the surfaces of processing equipment is usually contaminated with micro-organisms and, as indicated elsewhere, the cleaning stage should (in theory) remove all soil. Thus, any residual matter is an excellent medium in which micro-organisms can grow and multiply and sanitisation of the process equipment becomes a necessity in order to destroy such organisms, otherwise the keeping quality of yoghurt produced on subsequent days could be reduced. The effectiveness of the sterilisation process (using heat or chemical agents) is mainly dependent on the efficiency of the cleaning cycle. For example, any residual soil can become baked onto the contact surface to the extent that it becomes difficult to penetrate the soil in order to destroy the micro-organisms. Furthermore, the residual soil affects the subsequent cleaning process in the first instance because the active concentration of any chemical sanitising agent will be reduced and disinfection becomes less effective, and second, because it is possible that large numbers of micro-organisms may survive the sanitation stage and multiply in the soil; in such cases, infrequently used equipment may become heavily contaminated.

Effective sanitisation of processing plant is therefore directly governed by observation of the following points:

- Maintain the correct cleaning cycle prior to the sanitisation stage.
- Follow the recommendations laid down for the sanitisation method adopted, e.g. strength of the chemical solution, correct contact time and temperature.
- Usually the processing equipment is sanitised directly before use, and hence after the cleaning stage the equipment must be properly drained or purged with air, otherwise the moist condition, in the presence of any residual "soil", can encourage micro-organisms to multiply; if sanitised equipment is not used within a few hours, it is recommended that it should be resanitised before use.
- Any yoghurt plant has joints, valves, dead ends and rubber gaskets into which traces of soil and micro-organisms can penetrate and hence frequent dismantling of these components is essential; furthermore, heat sterilisation is more effective than chemical disinfection for reaching "blind" areas where micro-organisms could have penetrated.
- The hygienic condition of any yoghurt plant is governed by the rigour of the cleaning and/or sanitisation stages. For example, in a UHT plant, the aim is to render the equipment sterile before use, but for other types of plant, a "good sanitary" condition is acceptable by health authorities in many parts of the world. In fact, Zall (1990) differentiated between sanitisation and sterilisation as follows: "both treatments are aimed towards the destruction of micro-organisms, and the former aspect is more easily achieved as compared with sterilisation, which is more a rigorous and difficult procedure".
- The use of chemical disinfection agent(s) and/or compound(s) is subject to approval of the legal authorities concerned and in the United Kingdom a cumulative list is provided periodically by the Ministry of Agriculture, Fisheries and Food.

4.8 Methods of sanitisation and/or sterilisation

The methods which can be employed to achieve either sterilisation or sanitisation include the following.

4.8.1 Heat

Heat is normally applied as dry heat or moist heat. A hot oven used for the sterilisation of laboratory glassware at a temperature above 150°C for not less than 2 h provides an example of the use of dry heat. For practical reasons, dry heat is not used to sanitise yoghurt processing equipment, but moist heat is widely used, for example:

- autoclaving (steam under pressure)
- steaming or tyndallisation
- hot water
- steam (free flowing).

The first two methods are used for sterilising microbiological growth media and/or the medium for propagation of the starter cultures (e.g. the mother or feeder stage). The principles of these two methods are discussed in detail by Meynell and Meynell (1970). In an autoclave, steam under pressure is used and the recommended working condition is 121°C for 10–15 min (under a pressure of 0.1 MPa). However, the steaming method, which was introduced by Tyndall in the 1870s, consists of heating liquids up to 100°C for a few minutes so that all the vegetative microbial cells are destroyed. The liquid is cooled to ambient or 30°C to induce the spores to germinate and, after a few hours, the steaming/cooling cycle is repeated again. Further repetition of the heat treatment ensures destruction of all the viable spores in the liquid.

The steaming of milk is also practised in laboratories for the propagation of feeder starter cultures in flasks up to three litres capacity, but in this case only one heating operation is required.

Processing plant can be sterilised or sanitised using hot water or steam and the efficiency of the process is primarily dependent on three factors, the time–temperature combination (i.e. the temperature reached and the time for which the temperature is maintained), the humidity and the pressure.

The on-site applications of hot water circulation or steam (free flowing) for sanitising yoghurt equipment are illustrated in Table 4.9. Hot water circulation is most widely used. The limited application of free flowing steam is because (a) there are heat stresses generated that can cause pipelines to buckle or crack, (b) the intense heat generated can result in cracks in welded seams and can damage rubber gaskets, (c) since steam cannot be recirculated, its generation is a waste of energy, (d) the process is very noisy, and (e) the use of steam may pose a hazard to personnel. However, steam under pressure may be used to sterilise plants for the manufacture of UHT yoghurt.

However, a mixture of hot air and steam (*c*. 250°C) can be injected to sterilise yoghurt containers before filling and the process has been patented in Germany (Ammann, 1981). Such a process would, of course, be limited to certain materials due to the high temperature used, but unfortunately no specific type of container has been mentioned.

Table 4.9 Effectiveness of sterilising/sanitising yoghurt equipment using different methods of heating

Type of heating	Working application	Comments
Dry heat		
Hot air in a dry oven	>150°C for a least 2 h	Inactivates bacterial spores and is normally used to sterilise glassware.
Moist heat		
1. Pasteurisation	72°C for 15 s	Inactivates mesophilic micro-organisms including pathogens, psychotrophic bacteria yeast and mould (some mould spores are heat resistant). This method is not practised for the sanitisation of processing equipment.
2. Hot water	85°C for 15–20 min	Inactivates all vegetative cells (including thermoduric bacteria) with the exception of spores and bacteriophages; this method is recommended for sanitising processing plants.
3. Boiling water	100°C	As (2) above. Limited in its application but it is used for disinfection purposes; bacteriophages are inactivated.
4. Steaming	100°C for 10 min (2–3 cycles)	As (2) above. Efficiency is dependent on spore germination; it is not used for plant disinfection.
5. Steam (free flowing)	100°C	Not more effective than boiling water and bacterial spores are not inactivated. Used to sterilise milk churns for 1–2 min, or storage vessels until the condensate reaches 85°C – 10 min treatment.
6. Steam under pressure	121°C for 10–15 min (about 0.1 MPa)	Achieves proper sterilisation, but this method can only be used to sterilise growth medium, e.g. starter culture milk or agar.

Data compiled from BSI (1977), Meynell and Meynell (1970) and Zall (1990).

4.8.2 Chemical agents

Many chemical preparations can be used as sterilising agents and such compounds are used either alone (i.e. as sterilant) or combined with other chemicals (e.g. detergent/sterilisers). The former type is more widely used in the yoghurt industry and the efficiency of these chemical agents is influenced by the following factors:

- concentration of the chemical compound(s) in the sterilising solution,
- contact time between the chemical solution and the surfaces of the processing equipment,
- temperature and pH of the chemical disinfectant,
- amount of residual soiling matter in the processing equipment,
- type(s) of micro-organisms being inactivated,
- hardness of the water,
- inactivation by combination with residual detergent.

According to BSI (1977, 1984), chemical disinfectants which are commonly used in the dairy industry are as follows.

4.8.2.1 Chlorine

The most common source of chlorine is hypochlorite (sodium or calcium). These chemical compounds may be obtained in liquid or powder form and their bacteriocidal effect is due to the release of chlorine which is normally in the range 50–250 $\mu g\,ml^{-1}$ depending on the application.

Chlorine compounds in the undiluted form are corrosive to equipment and can be hazardous to health and should always be handled with care and at the correct concentrations. The following aspects may also be considered:

- Rinse the equipment thoroughly after the detergent wash, i.e. before circulating the hypochlorite solution.
- If an acid wash is incorporated into the cleaning cycle, the post-acid programme will be: (a) rinse with water, (b) rinse/wash with alkaline solution to remove all residues of acid, (c) rinse with water, and (d) sanitise with hypochlorite solution.
- Owing to the corrosive nature of chlorine, the sterilisation of utensils and equipment is often carried out immediately before use.
- The recommended working concentration is 200–250 $\mu g\,ml^{-1}$ at 40°C for 10 min or for 15 min at ambient; at higher temperatures, the chlorine volatilises and loses its bacteriocidal effect.
- The concentration of a sterilising solution of hypochlorite must always be checked to maintain its bacteriocidal power.

Although not normally used in the dairy industry, other forms of chlorine which could be used for sterilising purposes are elemental chlorine (available in a gas cylinder) and chloramine-T; the latter compound has a slow acting bacteriocidal effect compared with the inorganic sterilising agents. The combined detergent/sterilisers contain chlorine in the form of dichlorodimethyl hydantoin and/or sodium dichloroisocyanurate and the upper working temperature is around 70°C.

4.8.2.2 Quaternary ammonium compounds (QACs)

These compounds are basically cationic, surface-active bacteriocidal agents, for example alkyldimethylbenzyl ammonium chloride (benzalkonium chloride). QACs are sometimes used as detergent/sterilisers but, as the formulation is dictated by the needs of the manufacturer rather than the user, it should be noted that certain alkaline compounds (anionic wetting agents) can reduce the bacteriocidal action of QACs. It should also be noted, regarding QACs, that:

- They are stable in concentrated form and have a long shelf life.
- In concentrated form they are much safer to handle than hypochlorite solutions and they are relatively non-corrosive to metals.
- Owing to their high surface activity, excessive foam can be produced during circulation through the plant and hence QACs are sometimes difficult to rinse away.
- Factors that can impair their bacteriocidal effectiveness are the presence of organic matter, water hardness which can reduce their activity and the type of organism; that is, Gram-negative bacteria like coliforms and psychotrophic organisms may be less affected, especially at low concentrations (e.g. at $<50\,\mu g\,ml^{-1}$ of QAC at 10°C), than Gram-positive bacteria (e.g. staphylococci and streptococci) and a buildup of organisms resistant to QACs may develop in the plant.

- Recommended concentrations vary from 150 to 250 μg ml^{-1} of QAC at >40°C for a contact time of not less than 2 min.

4.8.2.3 Iodophores

The bacteriocidal compound is iodine which has been combined with a suitable non-ionic surfactant to provide a usable product; the iodine complex is acidified with, for example, phosphoric acid for better stability and improved bacteriocidal effect. Iodophores are often considered as detergent/sterilisers due to the presence of surface-active agents together with the acid, and in general:

- The recommended level in solutions is 50–70 μg ml^{-1} of free iodine in water of moderate hardness and the pH of solution should be around 3; hard water can neutralise the acid in the iodophore.
- Iodophores have a good shelf life at ambient temperatures, but some iodine may vaporise; however, excessive loss occurs at temperatures above 50°C.
- Some plastic materials, e.g. gaskets, can react with iodine and the product can acquire an iodine taint.
- Iodine stains any residual soiling matter on the surfaces of equipment and visual inspection of the plant can indicate the standard of hygiene.
- Milk residues can inactivate the iodine and an early indication of this loss is the fading of the amber colour; therefore, always check the strength of the iodophore, especially if the solution is recirculated.

4.8.2.4 Miscellaneous sterilising agents

Amphoteric (ampholytic) surface-active agents are known to have good detergent/steriliser properties, but due to their high foaming characteristics, they are not recommended for CIP. However, they are used for manual cleaning, since they are non-corrosive and non-irritant to skin.

Acidic sterilising agents are formulations that consist mainly of inorganic acids (e.g. phosphoric acid) and an anionic surfactant. They are used as combined detergent/sterilisers, or as sterilising agents per se. The latter type has a strong bacteriocidal action, albeit generally slower than hypochlorite and the sterilising effect is due to the highly acidic conditions produced at normal concentrations (e.g. pH 2). However, this low pH may be corrosive to metals, since it is equivalent to the acid wash employed to remove milkstone.

Sodium hydroxide (caustic soda) has a bacteriocidal effect due to its high alkalinity. Concentrations of 15–20 g l^{-1} at 45°C for 2 min are sufficient to inactivate non-spore forming organisms. An improved sterilising action is achieved at higher temperature (e.g. >70°C) and may be used for washing glass bottles.

Mixed halogen compounds containing chlorine and bromine can be employed and due to the synergestic effect, these halogens can be employed as sterilants at lower concentrations than the individual elements.

Formaldehyde is used for sterilising and/or storage of membrane plants.

Hydrogen peroxide (H_2O_2) is used in some parts of the world for the chemical sterilisation of milk. Although a large number of vegetative bacterial cells are destroyed, spore formers (aerobic and anaerobic types) survive. However, in the present context, hydrogen peroxide can be used for the sterilisation of packaging material (e.g. aseptic types from Tetra Pak, Gasti and Pure Pak). Either the packaging material is passed through a bath of H_2O_2 solution (e.g. Tetra Pak) or the

finished carton is "fogged" with a mist of H_2O_2 (e.g. Pure Pak). The solution contains a 15% concentration of H_2O_2 and the carton is then heated (i.e. hot air 80–90°C) to remove any remaining H_2O_2; however, concentrations up to 30% have been reported by Hahn (1981) for sterilising plastic yoghurt cups and up to 1500 $\mu g\,ml^{-1}$ is recommended for sterilising RO plants. Since H_2O_2 is a strong oxidising agent and potentially explosive, it is advisable to handle it with extreme care.

Non-acceptable types of sterilising agents are used for general disinfection and/or sterilisation purposes, but are not normally used in the dairy industry; their inclusion in this section is for information only. Examples of these compounds are:

- lysol and other phenolic compounds,
- heavy metals (e.g. mercury, zinc, silver, lead and copper),
- volatile disinfectants (e.g. liquid ethylene oxide, β-propiolactone or chloroform),
- alcohols are of limited application (i.e. for sterilising laboratory utensils).

4.8.3 Filtration

The sterilisation of liquids can be achieved by filtration, but it is the treatment of air which is of real significance in the yoghurt industry. Air filters are normally fitted in a starter culture laboratory, so that the air is cleaned of the majority of dust particles, bacteria, yeast and fungal spores. Special filters are also available to trap airborne bacteriophages. The sterility of the culture propagation room is further maintained by having the pressure of the filtered air in the room slightly above atmospheric so that, on opening the starter room or the yoghurt processing and packaging areas, pressurised air passes outward, so preventing unfiltered air from entering the sterile area.

4.8.4 Irradiation

Irradiation can be used in the laboratory and the processing area to maintain a clean atmosphere and ultraviolet (UV) radiation, in particular, has been used with success. The wavelength of UV has to be less than 400 nm and more than 180 nm (*c.* 260 nm), to be effective; the latter figure (180 nm) is critical, since below 180 nm the radiation is absorbed by atmospheric oxygen. The effect of UV radiation on microorganisms is either inactivation or destruction, mutation, or the induction of phage growth in lysogenic bacteria.

Some practical applications in the dairy industry are sterilising the air entering a laboratory, starter culture room and/or processing area and sterilising packaging materials before filling (Anon., 1979). It must be emphasised that it is important to protect the eyes from UV radiation, because the microbiological wavelengths can cause damage.

4.8.5 Spraying, fogging or fumigation

Solutions containing active chlorine or formaldehyde can be sprayed/fogged into the atmosphere of an enclosed room with the objective of destroying aerial contamination in the form of bacteriophage particles and/or mould spores. However, excessive use of chlorine-based chemicals may result in severe rusting of exposed metal objects (e.g. window frames or steel beams), and fumigation with formalin

may be hazardous, especially when used in mixtures with potassium permanganate (BSI, 1977, 1984); as a precaution, always add formalin after a permanganate treatment and not before. It must also be stressed that the inhalation of low levels of active chlorine or other fumigants over a long period of time could lead to pulmonary damage in susceptible individuals and hence application of the technique must be carefully monitored.

There are, therefore, many different methods which could be employed for the sterilisation/sanitisation of yoghurt processing equipment, but by far the most popular methods are:

- sodium hypochlorite to sanitise milk storage tanks and yoghurt incubation/fermentation tanks;
- hot water circulation to sanitise the milk processing equipment and, possibly, the bulk starter tanks;
- chemical solutions to sanitise yoghurt filling machines;
- H_2O_2 or UV radiation to sanitise packaging materials;
- autoclaving to sterilise laboratory utensils and bacteriological media; glassware may be treated in a hot oven.

The ultimate choice of any method of sterilisation/sanitisation is governed mainly by the recommendations of the equipment manufacturer supported by the degree of hygiene required by the quality controller manager. Obviously variations exist between one yoghurt plant and another in respect of procedures for cleaning and/or sterilisation, but a summary of some recommended methods for sterilisation is provided in Table 4.10.

4.9 Kinetics and mechanisms of microbial destruction

The growth of micro-organisms is governed by such factors as moisture content of the growth medium, availability of nutrients including trace elements, the presence or absence of oxygen; pH and temperature. However, manipulation of these factors is used by dairy scientists and/or processors to control microbial growth in the manufactured product and achieve their destruction/inactivation during sterilisation processes, that is, the product or equipment.

The temperature range over which micro-organisms can survive runs from as low as –250°C to as high as 150°C or above, but in practice the limits are less extreme. The thermal death point varies from one bacterial species to another and the spore-forming bacteria are the most heat resistant; their destruction relies not only on the level of heat applied, but also on various intrinsic and extrinsic factors, such as the age and thermal resistance of the organisms, as well as the water activity, pH and type of substrate. The protective action of a substrate is especially important and it is for this reason that processing equipment must be free from any soiling matter in order to achieve an effective sterilisation.

The criterion of death of a micro-organism is usually equated with the loss of its ability to reproduce, including the inactivation of spores. Thus, as the temperature is gradually increased above the optimum growth condition of the organism, cell injury or stress starts to occur and these changes can ultimately lead to death. It is important to note, however, that although some injured cells may be unable to reproduce, they can become viable again once the damage has been repaired. This

Table 4.10 Guide to procedures recommended for sterilising/sanitising yoghurt plant and equipment

	When sterilising is carried out separately following cleaning						When cleaning and sterilisation are carried out as a combined operation using a detergent/steriliser							
	Heat		Chemical agents				Chlorine-based products				QACs		Iodophores	
							Alkaline		Neutral					
	Steam	Hot/ boiling water	Sodium hypochlorite	Iodophors	QACs	Amphoterics	Low foam	Average foam	Low foam	Average foam	Low foam	Average foam	Low foam	Average foam
Milk storage vessels	A	C	A	A	A	B	A	B	A	B	A	B	A	B
Heat exchangers	C	A	B	C	C	C	B	C	C	C	C	C	C	C
Homogenisers	C	A	C	C	C	C	C	B	C	C	C	C	C	C
Culture, fermenting and fruiting vessels	A	C	A	A	A	B	A	B	A	B	A	B	A	B
Cans and lids	A	C	C	C	C	C	A	A	A	A	A	A	B	B
Pipelines and pumps	B	A	A	A	A	B	A	A	A	A	A	A	B	B
Yoghurt bottle and carton filling and capping machines	B	B	A	A	A	B	A	A	A	A	A	A	A	A

A: Suitable. B: May be suitable; investigate thoroughly before using. C: Not suitable or not normally used.

After BSI (1977). Reprinted with permission of British Standards Institution, London, U.K.

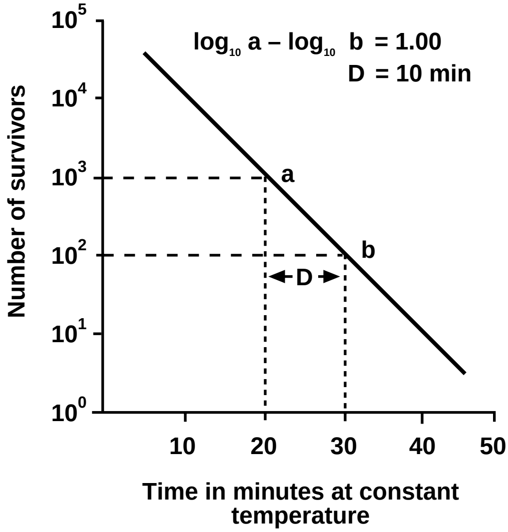

Fig. 4.12 Illustration of a hypothetical survivor plot
$Log_{10}a - log_{10}b = 1.00$; D = 10 min.

type of unpredictable behaviour highlights the complexity of thermoprocessing and although a few general points are discussed below, it is advisable that the field should be explored further (for example, Brown and Melling, 1971; Nickerson and Sinskey, 1972; Stumbo, 1973; Fellows, 1988; Burton, 1988; Pflug and Holcomb, 1991; Russell *et al.*, 1992; Pettersson *et al.*, 1996).

In pure culture and under ideal conditions, the death rate of micro-organisms is considered to be logarithmic. If the number of viable cells is plotted against time of exposure at a given temperature, a straight line will be obtained (see Fig. 4.12). From such a survivor curve the decimal reduction time *D* value can be calculated and according to Stumbo (1973), it is defined as follows:

> *D* value is the time required at any temperature to destroy 90% of the spores or vegetative cells of a given organism; numerically, equal to the number of minutes required for the survivor curve to traverse one log cycle; mathematically, equal to the reciprocal of the slope of the survivor curve.

It is important when *D* values are quoted that the temperature should be stated also. For example, if the temperature of exposure is 90°C then the *D* value is expressed as D_{90} = 10 min (see Fig. 4.12). According to Olson and Nottingham (1980), the straight line of Fig. 4.12 extends, in theory, below the base line, that is, into the area of negative logarithms, but in practice, of course, the number of organisms is rarely reduced to zero and hence there is always the probability of survivors. Thus a heat treatment (e.g. during the processing of food or the cleaning/sterilisation of equipment) is predetermined in order to obtain an acceptable level of microbial destruction.

Thermal death times are a measure of relative resistance of micro-organisms to different lethal temperatures. Figure 4.13 illustrates a hypothetical example. The

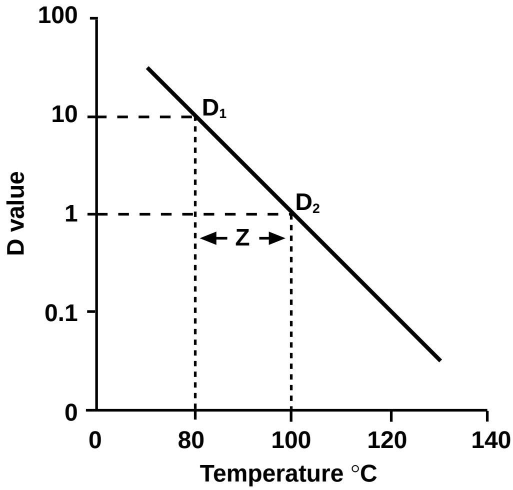

Fig. 4.13 Illustration of a hypothetical thermal death time plot
$\text{Log}_{10}D_1 - \log_{10}D_2 = 1.00$; Z = 20.

slope of the curve is referred to as the *Z* value and it is defined by Stumbo (1973) as follows:

> Number of degrees Celsius or Fahrenheit required for the thermal destruction curve to traverse one log cycle. Mathematically, equal to the reciprocal of the slope of thermal death curve.

Hence, both *D* and *Z* values can be used during the calculation of a heat process and the sterilisation effect is expressed as the *F* value which is defined by Stumbo (1973) as follows:

> The equivalent, in minutes at 121.1°C, of all heat considered, with respect to its capacity to destroy spores and vegetative cells of a particular organism.

An illustrated example of *F* value is the time in minutes required to destroy a specified number of spores at 121.1°C when $Z = 10$.

Another value which is sometimes considered in heat processing is Q_{10}, which is the ratio of the rate of one temperature to that at a temperature 10°C below it. Therefore the gradient $1/Z = \log Q_{10}/10$. The kinetic relationship between Q_{10} and *Z* is discussed in detail by Stumbo (1973). However, the mechanisms involved in the inactivation of micro-organisms by heat are considered to be chemical in nature. Rahn (1945) considered the logarithmic order of death of micro-organisms to be due to a loss of reproductive power. Since moist heat is more effective than dry heat, it is suggested that the heat energy results in extensive molecular disorganisation in the microbial cell and denaturation of the protein constituents and, in particular, the deoxyribonucleic acid (DNA) units responsible for cell reproduction. By contrast, mechanisms of inactivation by dry heat are not well established, but as reported by Meynell and Meynell (1970), could be due to a mutagenic action which gives rise to multiple lesions in the DNA.

Table 4.11 Mode of action of chemical sterilising agents against micro-organisms

Type of compound	Mode of action
Alcohol group	Possible actions are: • denaturation of proteins, or • interference with cell metabolism, or • lytic action
Phenol	Cause physical damage to the cell wall of organisms
Chlorine	Possible mechanisms are: • hypochlorous acid combines with the protein in cell membranes to produce certain compounds which interfere with cell metabolism, or • chlorine inhibits certain enzymatic reactions
Iodine	Possible mechanisms are similar to chlorine above

Bacteriocidal effect of chemical sterilisers is also affected by other parameters, e.g. pH, solvent composition and the presence of electrolytes. Data compiled from Zall (1990).

The biocidal mechanisms of each chemical sterilising agent are rather different and some relevant information is illustrated in Table 4.11.

4.10 Means of assessing the sanitary condition of a processing plant

Inspection of a yoghurt processing plant is a routine exercise which must be carried out in order to ensure that the cleaning and sterilisation operations are properly conducted. Different methods and/or techniques have been devised by quality controllers to monitor the sanitary condition of the plant, thus maintaining a good keeping quality of the manufactured yoghurt and at the same time meeting the requirements of the health authorities. The available methods of inspection are divided into the following categories.

4.10.1 Physical examination

This technique may involve the use of sight, feel or smell. The former two approaches can be useful to confirm the presence or absence of soil, since the absence of soil indicates that the plant has been adequately cleaned. However, the use of certain chemicals, a buildup of milkstone on plant surfaces, or merely wear and tear can affect the original shine of stainless steel. An acid clean can remove the layer of milkstone and leave a bright shiny surface, but not in the other cases. Although iodophores are not widely used, they offer one advantage in that any residual soil on plant surfaces becomes an amber colour and can then be detected by sight.

By contrast, unclean odours are indicative of inadequate cleaning and yoghurt incubation tanks that have not been properly sanitised can often be detected by smell alone.

A UV light (black lamp) can be useful to detect soil on clean plant surfaces, since where the rays are absorbed by inorganic and organic substances (e.g. calcium salts and casein) light is given off (Zall, 1990); the use of a "black lamp" should be complementary to other types of test performed by quality controllers.

4.10.2 Chemical examination

If detergent and sterilising agents are used for cleaning and sanitising purposes it is imperative that chemical tests of rinsing water are carried out to detect residues of these compounds. Thus, the presence of detergent and/or sterilant compounds could be directly related to a faulty CIP programme, because the final rinsing stage is either too short or not performed properly. Alternatively, it could reflect some fault in plant design, so that the cleaning and sanitising compounds are not being drained completely. The nature of the tests depends on the type of detergent and/or sterilising agent used. An example of one such test is the use of bromo thymol blue indicator on both the rinsing/drainage water and normal plant water (i.e. control). A colour change to yellow of the sample water indicates the presence of acid and a blue colour is due to alkali compounds. It is debatable whether or not pH measurement is reliable enough to detect traces of acid or alkali, but rinses containing high concentrations of these compounds can be detected easily using a pH meter.

4.10.3 Bacteriological examination

Microbial counts of plant surfaces, processing equipment and packaging materials are direct evidence of the hygienic quality of the plant. Different methods have been described for bacteriological examination of equipment, and examples of these can be found in BSI (1991) and APHA (1993).

Enumeration of total counts of bacteria, coliforms and yeast and moulds are the most popular microbiological examinations carried out and the types of microorganisms present reflect, to some extent, the standard of plant hygiene. The examination of processing equipment, packaging containers and other utensils for microbiological purposes can involve the swab technique, the rinsing method (or a combination of both) and/or agar impression plates (Lück and Gavron, 1990).

Swabs can be prepared either in the laboratory or purchased ready made from different suppliers; alternatively, agar contact slides could be used. In the rinsing method, a processing tank, glass bottle, milk churn or yoghurt container is rinsed with sterile water or Ringer's solution and the sample is analysed for total bacterial numbers or the presence of different types of organism.

In cases where the volume of rinse is large or the microbial load is low, it is advisable to filter a known volume of sample through an appropriate membrane, lay the membrane onto the surface of a pre-poured plate of nutrient agar, and then incubate; any micro-organisms trapped on the membrane should grow into visible colonies over 48–72 hours; the direct epifluorescent filter technique (DEFT) system (see Chapter 10) could also be adapted to examine rinse water.

Finally, two areas which must not be overlooked are the air and the general state of building (e.g. walls, drains, etc.) (refer to Chapter 3). Exposing agar plates to the atmosphere can prove helpful, especially during the summer months when the aerial mould spore level is high and an upward trend in counts can act as a warning of an increased risk of contamination of the yoghurt; the risks of infection by aerial spores

can be reduced by preventing draughts in the processing area. In addition, the general condition of the walls and floors in the processing and packaging areas provides an insight into the overall standard of hygiene.

Effluent treatment

4.11 Background

Water is used in the dairy industry for processing (e.g. heating, cooling, recombining powders) and cleaning purposes (e.g. equipment and dairy premises), and it is safe to assume that any waste water from processing will not contain as high a percentage of polluting materials as the water used for cleaning. This latter waste water or effluent has to be treated before it is discharged into the public sewer or into a river or water way and, from a yoghurt plant, the effluent will consist of milk base, dilute yoghurt and/or bulk starter culture, dilute fruit, dilute stabilising compounds and detergent and/or sterilising agents.

The volume of effluent arising in a dairy plant is dependent on two main factors, the type of dairy product being processed and the degree of water management being exercised and thus the amount of water being conserved. For example, cheese, milk powder and evaporating plants generate larger volumes of effluent than a dairy pasteurising milk, and ratios have been worked out in the dairy industry indicating the volume of water required to process a certain volume of milk. Unfortunately data concerning yoghurt production are not widely available, although the IDF (1981) did report the following water to milk ratios for the production of yoghurt in France: food grade water was 0.5–1.0 l^{-1} of milk, boiler water was 0.2–0.35 l^{-1} of milk and cooling water was 2.0–4.0 l^{-1} of milk. In addition, Hiddink (1995) reported on water consumption for liquid milk or desserts processing in some European countries and the water-to-milk ratios ranged between 0.5–12.9 $l\,kg^{-1}$ of milk. In view of the increased cost of water and effluent treatment, any reduction in water consumption is essential. This can be achieved by proper management (i.e. minimise water leaks from rubber hoses or recovery of the final rinse of the CIP cycle) reducing the demand of the cooling systems by, for example, using cooling towers and air coolers, and making extensive use of heat/cold regeneration in the processing equipment.

In view of the limited technical data available on yoghurt effluent, it is recommended that the reader consults the following International Dairy Federation documents (IDF, 1974, 1978, 1983, 1990, 1997d), Radick (1992), Strydom *et al.* (1993), Barnett *et al.* (1994), Tiwari (1994), Thakare *et al.* (1996), Samkutty *et al.* (1996), Viraraghavan and Varadarajan (1996), Kadam and Saxena (1996), Russell (1996) and Ordolff (1998) for general information regarding dairy effluent treatment.

4.12 Nature of pollution

A yoghurt effluent can contain organic and inorganic matter which is then subject to biological decomposition by micro-organisms. Oxygen is required for this biological process and if highly polluted water is discharged directly into rivers or other water ways, the dissolved oxygen in the water will be utilised. The result is that, in

extreme cases, life in the water reaches a standstill (i.e. stagnant water). The amount of oxygen required to decompose the total solids in an effluent is used, therefore, by major water authorities all over the world to assess whether waste water should be treated before discharge. The parameters used to assess the level of pollution in dairy effluents are as follows:

- Biological oxygen demand (BOD) is the amount or quantity of oxygen required by aerobic micro-organisms to decompose/stabilise the organic matter in effluent held at 20°C for 5–7 days. The sample is presedimented or filtered before conducting the test.
- Chemical oxygen demand (COD) is the amount or quantity of oxygen required for chemical oxidation. The effluent sample is filtered and/or sedimented, boiled in the presence of acid dichromate with silver sulphate as a catalyst and finally titrated. The organic matter reduces part of the dichromate and the balance is determined by titration. Hence, COD is a measure of the amount of oxygen absorbed by the dichromate.
- Permanganate value (PV) is a quick test to determine the chemically oxidisable organic matter in a sample. The effluent sample (sedimented and/or filtered) is boiled in acid or alkaline permanganate and the balance of unoxidised permanganate is determined by iodine titration. The presence of ferrous ions or nitrite in the sample can interfere with the accuracy of the PV test and hence this test is normally carried out before the BOD test as a preliminary indication of the magnitude of the oxygen demand.
- Total organic carbon (TOC) test involves the complete oxidation of all organic carbon constituents in the effluent sample to carbon dioxide.
- Total organic solids (TOS) content of the effluent sample is the difference between the total solids and the ash. The former is determined by drying at >100°C, and ashing takes place on heating the sample to >550°C.
- Miscellaneous tests may comprise the determination of fat, lactose and protein in a dairy effluent, and the level of surface-active agents (from detergent compounds). In the latter test, the sample is treated with methylene blue and, owing to the presence of anionic surfactants, insoluble blue salts are formed. The salts are extracted with chloroform and measured photometrically.

Other tests, which could be of some value in assessing the inorganic pollution likely from a yoghurt effluent, are pH, ammonia nitrogen, nitrate and nitrite, and phosphorus.

4.13 Methods of effluent treatment

A dairy effluent can be treated mechanically, chemically, biologically or by a combination of these methods. The mechanical treatment simply removes the insoluble matter from the effluent with the aid of filters, screens or sedimentation. Another mechanical system is flotation, in which air bubbles are passed through the effluent and, as they rise to the surface, small particles of solid matter become attached; the resultant scum can then be scraped off.

The use of certain chemical compounds (e.g. iron sulphate or chloride, or aluminium sulphate) can precipitate the dissolved constituents in the effluent, and the

precipitated matter is then removed by mechanical separation. However, chemical treatments cannot remove the lactose or other dissolved sugars.

Biological treatment of dairy effluents is widely practised and purification of any waste water is accomplished either by decomposition of the organic substance(s) by the aerobic activity of micro-organisms, or as the result of anaerobic fermentation. In the oxidative approach, the oxygen is supplied artificially by means of special aeration inlets, but a septic tank is required for the anaerobic process.

The treatment of any type of dairy effluent, including that from a yoghurt plant, is usually carried out using the combined processes of mechanical separation and biological purification and the overall process is divided into three main treatments:

- primary (effluent roughing)
- secondary
- tertiary (effluent polishing).

Figure 4.14 illustrates the different types of process employed for the treatment of effluents from yoghurt plants.

Data regarding the treatment of dairy effluents are not widely published, but a study carried out by Gaster (1972) on a plant producing fruit yoghurt is summarised in Table 4.12. Two biofilters were used and the effluent plant was capable of handling 550 000 l day^{-1}. Settlement of the effluent was carried out prior to the roughing stage and because of the nature of yoghurt (low pH) large volumes of sludge were removed. The reduction in BOD was about 75% and the filter beds were relatively small, compared with other creameries, since the greater part of the effluent load was being removed by the high rate biofilters.

Nevertheless, environmental issues and legislation have placed increased pressure on the dairy industry over the last few decades and Stevens (1986, 1993, 1995) has reviewed the legal aspects of dairy effluent treatment and control and developments in wastage control. However, according to Stafford (1992), anaerobic fermentation of the effluent prior to further treatment and discharge into the environment has two main advantages: first, the energy can be recovered and utilised, and second, the reduction in BOD/COD pollution consumes no oxygen; some

Table 4.12 Some data regarding the treatment of effluent from a yoghurt factory

Treatment and/or process	Capacity
Daily throughput	546 000 l
Balancing capacity	273 000 l
Roughing treatment	Two-stage flocor tower 590 000 l
Polishing treatment	Two filter beds, e.g. alternating double filtration (ADF) 271 000 l
	BOD load
Raw effluent	1000–1500 ppm (2400 ppm highest level)
To the plant	654 kg BOD day^{-1}
To biofilter	1.39 kg BOD m^{-1} day^{-1}
BOD reduction in roughing state	75–85%
To percolating ADF	0.28 kg BOD m^{-1} day^{-1}
Final effluent	15–25 ppm

Adapted from Gaster (1972).

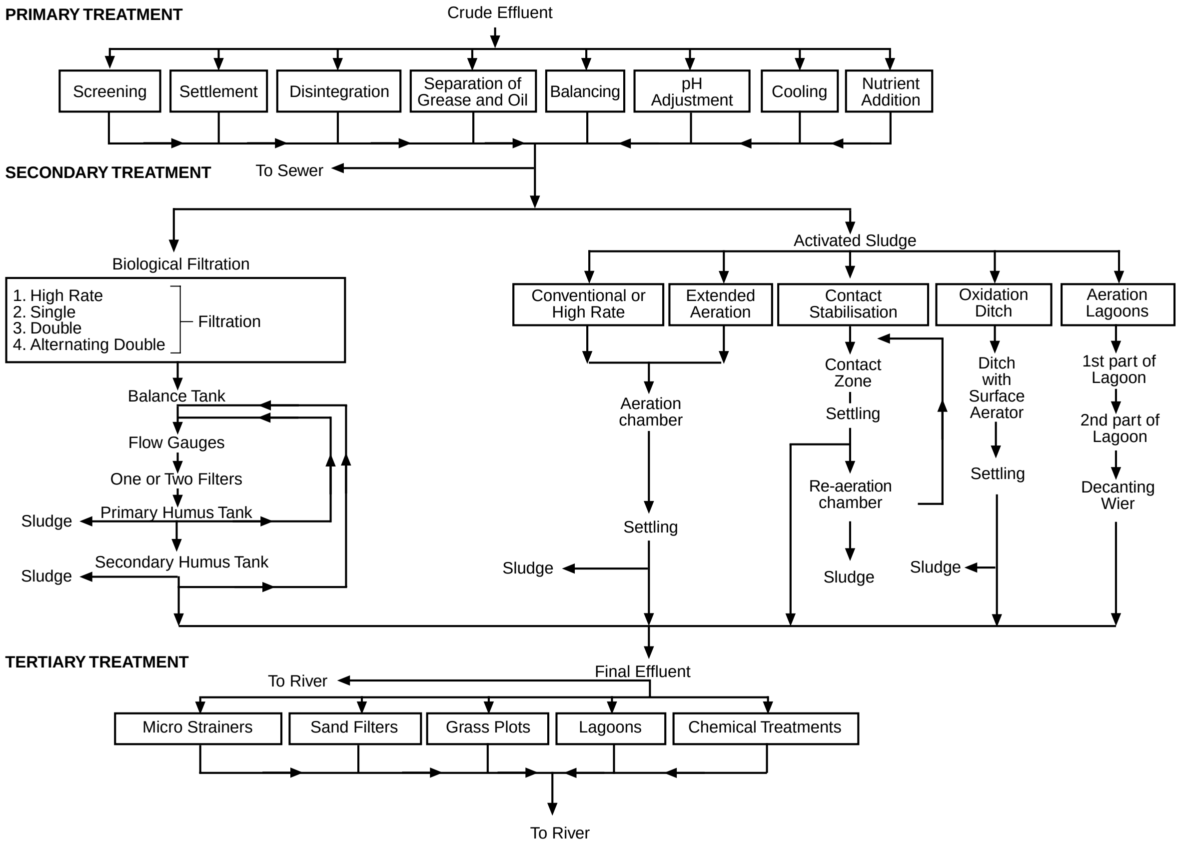

Fig. 4.14 Possible treatments of effluent from a yoghurt plant

Data compiled from Cooper (1974), Zabierzewski and Thom (1978), Synnott *et al.* (1978) and Odlum and McCarthy (1978).

aerobic polishing of the effluent will be required to meet the standards for river quality discharge. Under certain conditions, the aerobic biological treatment of dairy waste water results in poor sludge settling (i.e. bulking) due to the presence of highly soluble inorganic components and the high COD:N:P ratios (Donkin, 1997). The problem is minimised by extending the aeration time, and the incorporation of an anaerobic or anaxion zone to facilitate the degradation of the readily metabolised lactose in the effluent. Furthermore, sludge bulking has been associated with residues containing filamentous bacteria (Donkin, 1997; see also Nyhuis, 1994; Viraraghavan and Wise, 1994; Anderson *et al.*, 1994; Monroy *et al.*, 1995; Malaspina *et al.*, 1995, 1996).

Modification of an effluent treatment plant for a cheese factory in Sweden (i.e. the aeration basin was converted to an equalisation tank, trickling filters were replaced by moving-bed biofilm reactors and a new settling tank was added) achieved average removal efficiences of 98% of both total BOD and P (Rusten *et al.*, 1996). However, removal of fat, oils and grease from waste water can improve biological treatments and the target level should be <10 mg 100 ml^{-1}; the various methods that can be used have been reported (IDF, 1997d) (see also Cordoba *et al.*, 1995; Cordoba and Sineriz, 1997).

4.14 References

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